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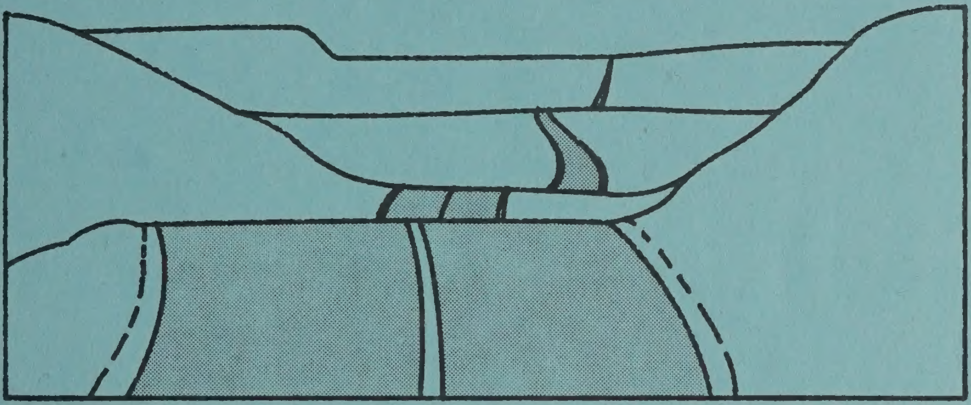
Department of Highways

Materials Bureau



DESIGN AND EVALUATION OF ™FOAMIX

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In cooperation with the
U.S. Department of Transportation
Federal Highway Administration
June, 1986

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16. Abstract

This report presents the findings and observations of both the design and construction of an experimental project constructed with Foamix (i.e., foamed asphalt, silty sand and water) pavement base in Southeastern Montana. Actually, this experimental project consists of three adjoining projects which form 23 miles of interstate highway. Information regarding the materials characteristics, design procedure, engineering properties, and relating to the subgrade preparation and plant mix surfacing is included.

Foamix is a material that has had relatively little use, especially in the United States, since its development in 1957. This report describes some of the problems associated with using this product as well as the advantages of paving material composed primarily of silty sands. Based on the early road performance and potential cost savings, this report concludes that Foamix has seemingly proved to be a worthy alternative to standard paving materials.

17. Key Words
Foamix pavement base, foamed asphalt/silty sand mixture, stabilized base course, alternative paving materials.

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MONTANA DEPARTMENT
OF HIGHWAYS
IN COOPERATION WITH
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL FOAMIX BASE
I-90 LODGE GRASS TO WYOMING BORDER

EXPERIMENTAL PROJECT NO. FHWA/MT 83-02
Construction Project No's.
ID 90-9(36)531 U-2
ID 90-9(62)543
ID 90-9(38)549 U-2

PART I
DESIGN

PART II
CONSTRUCTION

JUNE, 1986

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DISCLAIMER

The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the Montana Department of Highways or the Federal Highway Administration. The intent of this report was to develop design criteria and monitor construction to aid in the understanding and evaluation of Foamed-Asphalt Mixes.

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The research reported herein was performed in the Materials Bureau of the Montana Department of Highways in Helena, Montana. The testing and report writing was done under the guidance and supervision of Mr. Robert T. Rask, Supervisor, Physical Testing Section.

Appreciation is expressed to Mr. Robert Garber, Manager, Research Program. His suggestions aided considerably to the final context of this report.

The other members of the Materials Bureau who assisted in the research effort are also acknowledged.

Construction personnel from the Billings district provided substantial information pertaining to this report. Appreciation is expressed to Charles W. Klimper, District Construction Supervisor; Kenneth H. Neumiller, District Materials Supervisor; Don Kittleson, Project Manager; Ray Schaak, Project Manager; and all the other members of the Billings district who assisted in the project effort.

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PART I
DESIGN

SUMMARY

The Department needed alternative paving materials which could be used to make up for inadequate or non-existant paving aggregates in certain areas of the state. Three projects which make up a continuous 23-mile four-lane section of Interstate between Lodge Grass, Montana and the Wyoming border were a prime area for considering alternative paving materials. Consequently, after careful analysis, the Department elected to investigate Foamix, a process patented by Conoco Inc., as a base course for these projects.

Laboratory experimentation of Foamix began in Montana in September, 1983. The primary purpose of the Foamix laboratory research was to optimize the combination of foamed asphalt, moisture, and aggregate (silty sand) that would constitute Foamix with the most desirable engineering properties possible from the existing silty sands and available asphalt sources.

The purpose of foaming the asphalt is to increase the volume and surface energy of the asphalt to acquire effective coating of cold damp aggregates or soils. By foaming the asphalt, the viscosity is reduced allowing greater dispersion of the asphalt into the aggregate. Foamed asphalt is obtained by injecting cold atomized water into hot asphalt. This liquid material is then immediately mixed with premoistened aggregate (e.g. silty sand) to create Foamix.

A number of different tests were used to evaluate the engineering properties of Foamix. These tests include freeze-thaw, indirect tensile, resilient modulus, bulk specific gravity, water absorption, and Marshall stability and flow. In addition, a number of different asphalts were tested for their foaming characteristics (i.e., foaming ratio and half-life). Road Rater deflection and Mays ride meter tests were also used to evaluate the in-situ Foamix.

All of the mixes tested had better results when the silty sand contained a high moisture content (80% to 90% of optimum moisture) prior to adding the foamed asphalt. However, Foamix that contains too much moisture (95+%) was difficult to lay down due to the cohesive nature of wet sand. Foamix made from silty sand that contains low moisture prior to adding foamed asphalt was found to have asphalt inadequately coating the soil particles, thus creating

moisture susceptible asphalt mixes. Therefore, moisture content plays an important role in producing Foamix. Although no curing is required before compaction, Foamix does need adequate curing following compaction to improve coating and strength characteristics.

Due to the size of this experimental project, to date the world's largest Foamix construction project, time was available for determining what construction methods work best in producing Foamix. For instance, Foamix spread by a motor patrol resulted in a much better operation than Foamix spread by a paving machine, and pneumatic tired rollers produced better compaction than did steel wheel rollers. Also, the type of mixing equipment and the method of mixing greatly affected the Foamix test results. This emphasizes the need of effective mixing equipment for field Foamix production.

Finally, a minimum savings of $4,000,000.00 was obtained by using Foamix for the combined three projects. The major cost savings were due to the elimination of aggregate hauling and heating costs. Thus, for these projects, Foamix proved to be an economical alternative to standard paving construction techniques.

INTRODUCTION

Laboratory experimentation with a patented process known as Foamix[1] began in Montana in September 1983. Work was performed in the Materials Bureau laboratory of the Department of Highways in Helena, Montana. The Department had found it necessary to search for alternative paving materials which could be utilized in areas of the state with inadequate paving aggregates. A preliminary cost estimate for the Lodge Grass - South and Wyoming Line - North projects revealed that the surfacing cost was extremely high. The surfacing design work was originally completed by a consulting firm in 1971 which recommended full-depth asphaltic concrete sections 13 inches and 15 inches thick with an asphaltic membrane treatment for swelling soils. At the time, this was thought to be the most economical section because of the low cost of asphalt cement, lack of aggregate, and soil conditions of the area. The price of asphalt cement averaged $38 per ton at that time; the subsequent increase to $210 per ton was the major factor contributing to the high surfacing cost.

---

[1] Foamix is a trademark of CONOCO INC.

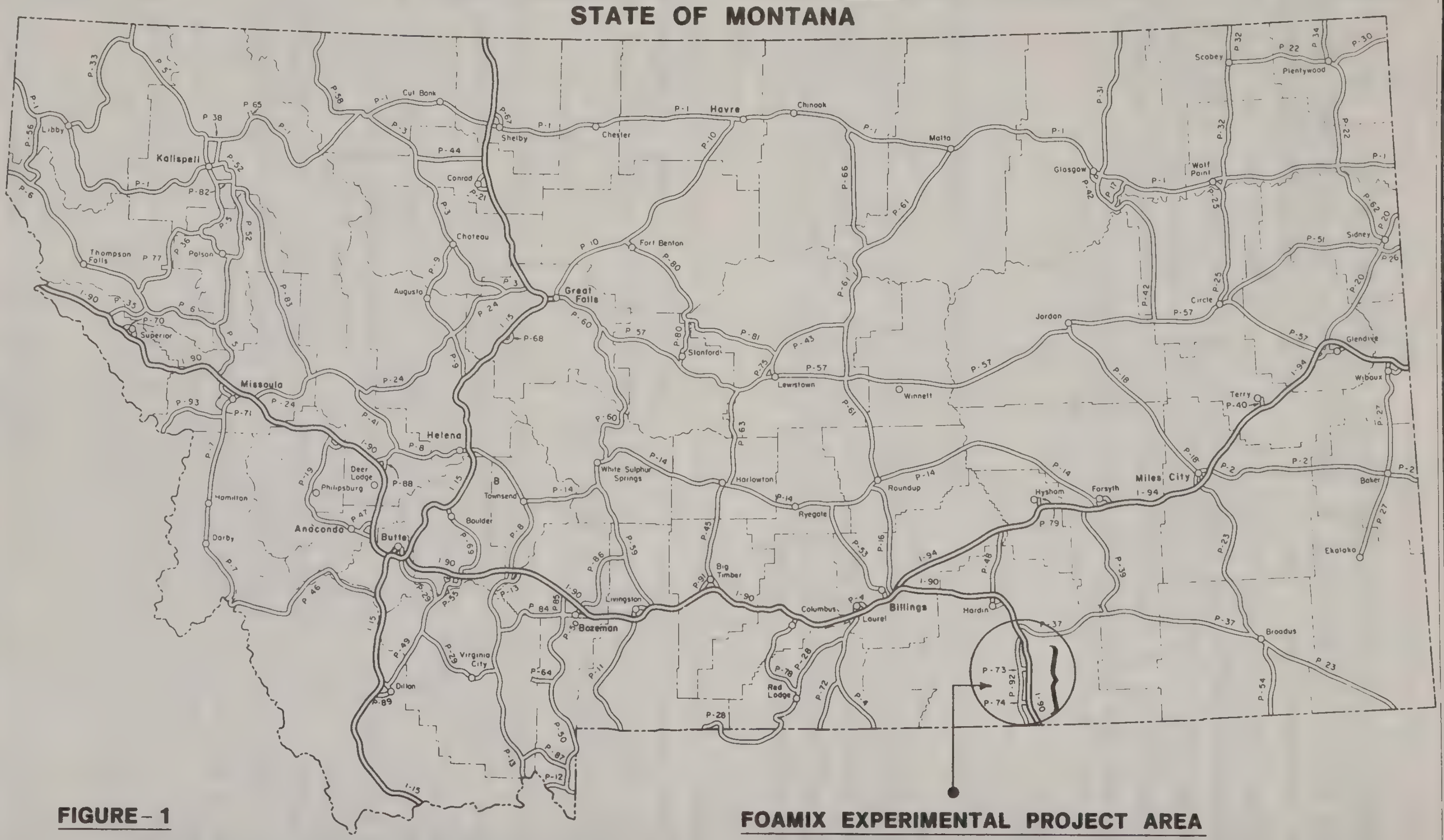
Consequently, a value engineering team was commissioned in June, 1981 to investigate possible alternatives to typical pavement design methods, particularly in connection with a section of Interstate 90 in southeastern Montana (i.e., Lodge Grass South and Wyoming Line North). After careful analysis, the team recommended that foamed asphalt be used as a base course for the Interstate 90 projects. The experimental Foamix base was eventually included in three projects along a 23-mile, four-lane section of Interstate between Lodge Grass, Montana and the Wyoming border (refer to Figure-1).

BACKGROUND

In 1957, Professor Ladis Csanyi of Iowa State University demonstrated the effectiveness of combining foamed asphalt with marginal aggregates to achieve low-cost stabilized mixes. The process consisted of foaming the asphalt by injecting steam at about 40 psi into hot asphalt. This process was later modified by Mobil of Australia which used approximately 1.5 to 2.5% cold atomized water injected into hot asphalt.

The purpose of foaming the asphalt was to increase the volume and surface energy of the asphalt to acquire effective coating of cold damp aggregates or soils. By foaming the asphalt, the viscosity is reduced allowing greater dispersion of the asphalt into the aggregate.

Foamix is a process developed to provide a quality base when using marginal aggregate. This process does not require heating or drying of the aggregate, and less asphalt cement than a hot mix operation is required. With an "R" value of 70 or greater, the structural number of Foamix is 2.64 per foot whereas the structural number of a grade B plant mix surfacing course is 4.0 per foot, and a fully treated asphalt base is 3.0 to 3.6 per foot. Thus, Foamix is not intended to replace plant mix surfacing nor is it intended to replace a fully treated asphalt base. The Foamix used for these projects is designed to act only as a quality stabilized base material.



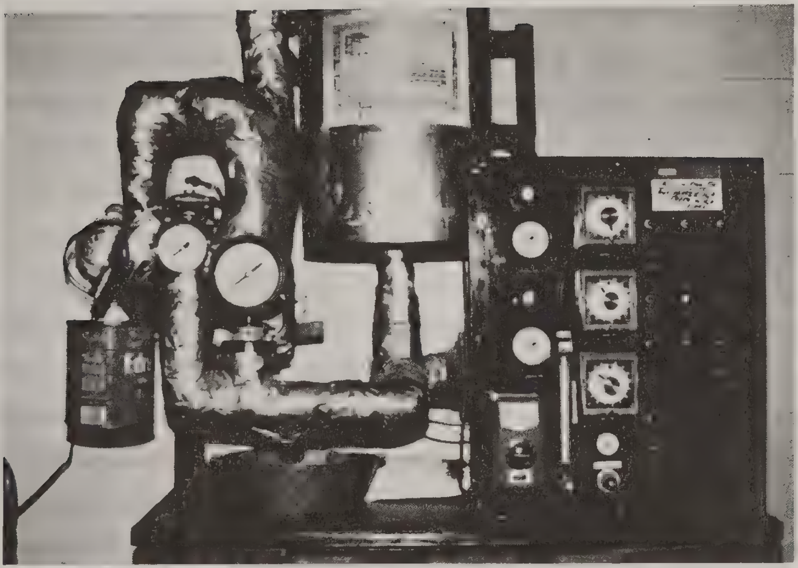
STATE OF MONTANA

FIGURE-1

FOAMIX EXPERIMENTAL PROJECT AREA

A laboratory foaming device (refer to Figure-2) manufactured under patents owned by Conoco, Inc., was used for this study. The device consists of a heated two-gallon storage tank of asphalt which is circulated at a constant rate of 0.5 gpm. An automated three-step operation produces foamed asphalt which simulates that obtained during field production.

FIGURE-2
LABORATORY FOAMING DEVICE



OBJECTIVE

The primary purpose of the Foamix laboratory research was to optimize the combination of foamed asphalt, moisture, and silty-sand soils to produce the most durable paving product possible. A secondary purpose was to develop a test procedure which would provide a reasonably accurate indication of the effects of mixing and lay down during actual construction. In addition, an indication of probable future performance of the Foamix pavement was desired. Physical tests were used to determine moisture susceptibility, freeze-thaw resistance, and strength of Foamix. Testing included Marshall stability and flow, resilient modulus, indirect tensile, water absorption, bulk specific gravity, and freeze-thaw tests.

The experimental section, approved in accordance with the procedures of FHPM 6-4-2-4, consists of a two-foot sand subbase, two 4½-inch lifts of Foamix, four inches of plant mix surfacing, and 3/4 inch of open graded friction course. Road Rater[2] deflection, rideability, and measurement of cracks and ruts were used in monitoring the projects following construction and will be continued several years in the future. In addition, Foamix moisture measurements and physical tests from plant mix cores will be used to monitor the projects.

MIX DESIGN PROCEDURE

After months of experimentation in the laboratory, the type of mixing paddle used was found to greatly affect the overall results of the mix. Originally, a loop wire whip paddle was used for mixing and the Marshall specimens appeared to be interlaced with asphalt spots. With the subsequent use of a large flat paddle mixer, however, Marshall specimens appeared to have asphalt evenly distributed throughout the mix. This improved the moisture susceptibility of the mix immensely. Most specimens made from the mix using the loop wire whip would not hold together for the required 30 minutes in a 140°F water bath (standard Marshall stability test procedure), whereas specimens made from the mix using the large flat paddle held together satisfactorily under the prescribed conditions. An example of the difference in Marshall stability of compacted specimens with the different mixing paddles is as follows:

---

[2] Road Rater is a trademark of Foundation Mechanics, Inc. (refer to Fig 17, p 106).

1) Soil No. 559642, 90% Optimum Moisture Content (OMC), 6.1%* Asphalt Content (AC), loop wire whip
   Average stability = 122 lbs.
2) Soil No. 559642, 90% OMC, 5.9% AC, flat paddle
   Average stability = 2120 lbs.

* From herein, all referral to asphalt content and moisture percentiles are based on aggregate dry weight.

This illustrates the importance of thoroughly mixing the asphalt and silty sand during field application. It may also suggest a need to investigate the various types of mixing equipment used in the production of Foamix under actual field conditions.

After mixing numerous batches of Foamix, 4000 g dry weight batches were found to be about the maximum amount which could be handled in the ½ H.P. Reynolds Electric Planetary Mixer without the motor stalling. Therefore, all batches were made with a silty sand dry weight of 4000 g which was enough to produce four 1050 g Marshall specimens from each batch. There was also a small amount of mix left over which was retained for visual examination.

The mixing procedure consisted of mechanically mixing batches for one minute at slow speed followed by one minute of hand mixing and then one final minute of slow speed mechanical mixing. Most Marshall specimens were compacted directly after mixing (50 blows/side) although some were compacted the following day. The mix that was compacted the following day was stored in an airtight container overnight which did not seem to affect the results.

The original oven/air curing period for Marshall specimens was three days at 140°F or three days at 120°F. This was in accordance with Professor Lee's (Iowa State University) method of testing. Since this material is being used as a base material only and is not subject to extreme heat, it was decided to use 96°F for three days as the standard oven/air curing conditions.

Stepwise procedure for Foamix mix design was established as follows:

1) Determine the moisture content present in the silty sand.

2) Determine the gradation (Modified AASHTO T11-88 and T27-78), Atterberg limits (AASHTO T89-76 and T90-70), specific gravity (AASHTO T-100), maximum density/optimum moisture content (AASHTO T-99), and soil classification (AASHTO M145-73).
3) Determine the R-value of the soil (AASHTO T190-78).
4) Determine the foaming ratio and half-life [3] of the asphalt. Test at temperatures of 300, 325, and 350°F with water-asphalt weight ratios of 1.5, 2.0, and 2.5% for each test temperature. If foaming characteristics do not meet our special provision limits, use a chemical product to neutralize the antifoaming agent in the asphalt and repeat testing.
5) Establish the asphalt foaming temperature and water-asphalt weight ratio to be used during testing.
6) Prepare three 4000 g (dry weight) batches of Foamix for asphalt contents of 3.5, 4.5, 5.5, and 6.5% at moisture contents of 70, 80, and 90% of optimum. Add the desired amount of water to the silty sand and mix thoroughly just prior to adding foamed asphalt. Run a two second waste cycle[4] before the addition of asphalt. Actual asphalt content in the mix is determined by weight difference of the mixing bowl plus contents before and after adding asphalt. Asphalt clinging to the mix bowl is corrected by adding an extra 50 to 70 g of asphalt to each batch.
7) With room temperature Marshall hammers, mold the Foamix material into ten Marshall specimens for each asphalt/moisture content.
8) Perform a Proctor compaction test on the remaining material and calculate the maximum wet density.
9) Cure seven specimens of each type of mixture for three days at 96°F. The remaining three specimens are used as non-cured test specimens.

---

[3] Foaming ratio and half-life are defined on page 10, paragraph three.

[4] Waste cycle -- Foamed asphalt is sprayed into a waste container to ensure the foaming chamber is refilled since it will drain if more than five minutes elapse between foam production cycles. Repeat waste foam cycle if time between foam cycles exceeds five minutes.

TEST PROCEDURE

NON-CURED SPECIMENS

Perform the resilient modulus test at 55°, 73°, and 96°F. If testing is not performed immediately after removal from the molds, keep specimens in an airtight container and place in a 55°F water bath. This is to avoid curing of the briquets. Allow specimens to stabilize temperature wise two hours at 73°F and 96°F but no longer than three hours before testing. Immediately after the resilient modulus (M_R) test, perform a tensile split test with the specimen. Note: the resilient modulus and tensile split test are described on pages 19 and 24, respectively.

CURED SPECIMENS

1) Perform the M_R test with individual specimens at 55°, 73°, and 96°F.
2) Immediately after the M_R test of each of the three specimens, perform a tensile split test with each specimen to insure that the specimen is still at its designated test temperature of 55°, 73° or 96°F.
3) Perform the Marshall stability and flow test on two specimens and average the results.
4) Perform a bulk specific gravity and water absorption test on one specimen. If specimen is in good condition after four-days absorption in the water bath; test for the retained Marshall stability.

5) Perform a freeze-thaw test (freeze in air at least 4 hours; thaw in water at 55°F for 30 minutes; repeat test cycle) on the remaining cured specimen. Record the number of cycles at which the specimen begins to disintegrate (describe cracks, total breakup, etc).

To evaluate the test results, construct graphical plots of tests 1 through 5 for the cured specimens versus the asphalt content of each specimen at its respective moisture content. In addition, construct graphical plots of the resilient modulus and tensile stress results of the non-cured specimens. If any anomalies, unexpected results, or indications of unsatisfactory properties are found, repeat the test. After a design has been chosen, mix two batches of Foamix at design specifications and run an R-Value. Mold three specimens from the remaining material. Cure the specimens one, two, and three days, testing for stability each day. This will aid in determining the time necessary to reach minimum strength requirements before loading is applied.

MATERIAL CHARACTERISTICS

Special provisions set up by the department required that the silty sand used for all three projects be non-plastic, A-2-4(0), with 100% of the material passing the 4 mesh sieve and 10 to 30% passing the 200 mesh sieve. Most of the material tested had approximately 20% passing the 200 mesh screen. The optimum moisture content of the material ranged from approximately 14 to 19% by weight. The majority of the silty sand soil tested had an R-value of 60 and an optimum moisture content of 17.0% with a maximum wet density of 108 lbs./ft.^{3}. A minimum R-value of 45 was necessary to meet the Department's special provision requirements.

The special provisions require an asphalt foaming ratio of 10 to 15 and a minimum half-life of 20 seconds. Foaming ratio is the maximum foam volume to the volume of asphalt remaining after the foam has settled. Half-life is the time in seconds for the foam to settle to one-half of the maximum foamed level attained.

Two different sources of asphalt were originally used for testing, but since one asphalt did not meet our desired foaming requirements, a third asphalt source was later tested. Three penetration grades of asphalt were used for testing which included: 85/100, 120/150, and 200/300. Because one source did not meet the foaming characteristics required in our special provisions, a chemical counteractant to neutralize the anti-foaming agent in the asphalt was added at approximately 0.45% by weight of asphalt. The "counteractant" which was used consists of 2/3 thin oil and 1/3 magnesium stearate. It was found that certain silicone products are added to some asphalts at the refinery specifically to reduce or eliminate foaming.

DISCUSSION OF RESULTS

In the earliest Montana testing, Marshall specimens of Foamix could not withstand the 30-minute 140°F water bath cure which is part of the Foamix test procedure. After examining the premoistened soil material, it was determined that small lumps of soil were not penetrated by moisture. To hopefully correct this problem, the desired amount of water was added to some silty sand samples one full day before mixing and were kept in an airtight container. This did not improve the results. It was therefore decided to accept the dry lumps and thoroughly mix the water and soil immediately before adding the asphalt. This became the standard procedure and also minimizes the possibility of reducing the desired moisture content by evaporation.

Most Marshall specimens were disintegrating after 30 minutes in the 140°F water bath. Therefore, the specimens were cured in air at higher air temperatures (from 120°F to 140°F), at longer intervals (from three to four or more days), and at a combination of these, all before placing in the 140°F water bath. Some improvement was noted, but still not enough to proceed. Other experimentation followed, including variations of asphalt temperature, asphalt content, moisture content, soil gradation, water-asphalt weight ratio, sample size, mixing time, oven cure time and temperature. All of these failed to produce water resistant Marshall test specimens.

The mixing paddle was then changed from a loop wire whip type to a large flat paddle. This vastly improved the moisture resistance of the specimens. Also, the dry lumps were no longer noticeable. After this discovery, no significant problems with specimens were again encountered unless a low asphalt or low moisture content was used. The larger surface area of the flat mixing paddle seems to knead the material together, and to disperse the asphalt more uniformly within the mix. In any event, the change of mix paddles allowed the entire test program to proceed.

Various batches of Foamix were then tested with different amounts of moisture in the silty sand. Most of the mixtures tested had better stability/flow results at higher percentages of moisture (refer to Table 1). A range of 70 to 90% of the optimum moisture content was used for the test evaluations although one trial of Foamix was made at 110% of the optimum moisture level. Test results after oven curing with the high moisture were very good, but if material was not cured it would be very difficult to lay down in the field due to the cohesive nature of the mix at such a high moisture content. The mixes with low moisture were found to have asphalt inadequately coating the soil particles, thus creating extremely moisture-susceptible asphalt mixes.

TABLE 1

DIFFERENCES IN STABILITY AND WATER ABSORPTION OF COMPACTED SPECIMENS AT DIFFERENT SILTY SAND MOISTURE AND ASPHALT CONTENT LEVELS[1]

Percent of Optimum Moisture %	Asphalt Content (%)	Bulk Sp. Gr.	Water Absorption (%) 1 Hour	1 Day	4 Days	Average Stability (lbs.)	Average Flow (In.)
90	3.5	1.83	10.2	15.5	d[2]	330	0.23
90	4.3	1.85	8.0	14.5	15.8	812	0.205
90	5.3	1.87	3.0	7.5	9.9	2225	0.12
90	5.5	1.87	2.8	7.3	9.5	3250	0.12
90	6.0	1.84	2.5	7.0	9.0	2805	0.125
80	4.3	1.88	13.0	16.2	d	195	0.285
80	4.4	1.87	16.6	d	-	165	0.345
80	4.5	1.87	16.3	16.5	d	127	0.32
80	5.3	1.81	11.9	14.8	15.6	155	0.32
80	5.8	1.80	9.4	13.9	15.0	475	0.275
70	4.4	1.70	14.3	d	-	57	0.31
70	4.8	1.79	14.4	17.1	d	60	0.30
70	5.1	1.73	15.7	d	-	45	0.33
70	5.5	1.75	13.1	14.4	d	140	0.395
70	6.0	1.75	12.7	14.0	16.4	137	0.32

[1] All specimens were made with 320°F 120/150 asphalt, a 2.5% water-asphalt weight ratio, and cured 3 days at 120°F

[2] d - disintegrated

Mixes made with silty sand containing marginally low or high percentages of material passing the 200 mesh screen (but within the special provisions range of 10 to 30% of total aggregate by weight) were found to yield acceptable test results. Better results were obtained with the mixes containing a higher percentage of -200 mesh material than those made with lower percentages of soil material passing the 200 mesh screen. Stabilities were approximately 300 lbs. greater with mixes containing 29% material passing the 200 mesh screen than for mixes containing 13.4% material passing the 200 mesh screen.

A high water-asphalt weight ratio of 4.0% was used on a few mixes to determine whether it would improve results. Marshall stability dropped 300 to 500 lbs. from similar mixes made with a 2.5% water-asphalt weight ratio.

To determine the importance of adequate mixing time, the mixing time was cut in half. Results showed a decrease of approximately 50% in stability and an increase of at least 100% in water absorption of the compacted specimens when made with the shortened mixing time. Since the time and thoroughness of mixing in the field may be less than that used in the laboratory, laboratory mixing standards should be adjusted accordingly. Based on field test results, future Foamix laboratory mixing time will be slightly reduced from that used for these projects.

Although nearly all testing was performed with A-2-4(0) soil, one exception was a soil sample, Lab No. NC-19185, which was an A-3. This material was from the N.E.¼ of Sec. 4, R-23-E, T-17-N near Grassrange in Fergus County. The optimum moisture content was 16.0% with a maximum density of 97.7 $lbs./ft.^3$. The soil had an R-value of 72, was non-plastic, and had 5.7% passing the 200 mesh sieve. Due to the low percentage of fines (5.7% passing the 200 mesh screen), Marshall specimens were not cohesive enough to hold together. Thus, the material was not suitable for Foamix.

ASPHALT FOAMING RESULTS

Experimental foaming characteristics of various asphalts were measured in three-pound coffee cans. Two-second waste cycles were run twice before each test. Also, pre and post-water flush settings were adjusted to minimum values when testing.

The results of foaming ratio and half-life tests of Cenex 120/150 penetration asphalt (refer to Figure-3) show how a small change in the water-asphalt weight ratio changes the foaming characteristics of an asphalt. The testing of mixes using various water-asphalt weight ratios showed slightly better results with a 2.5% water-asphalt weight ratio as compared to those made at 2.0 and 1.5%. Since half-life met the minimum requirement (20 seconds) and foaming ratio was approximately 12-15 with a 2.5% water-asphalt weight ratio, this was found to be the optimum water setting for our mixes.

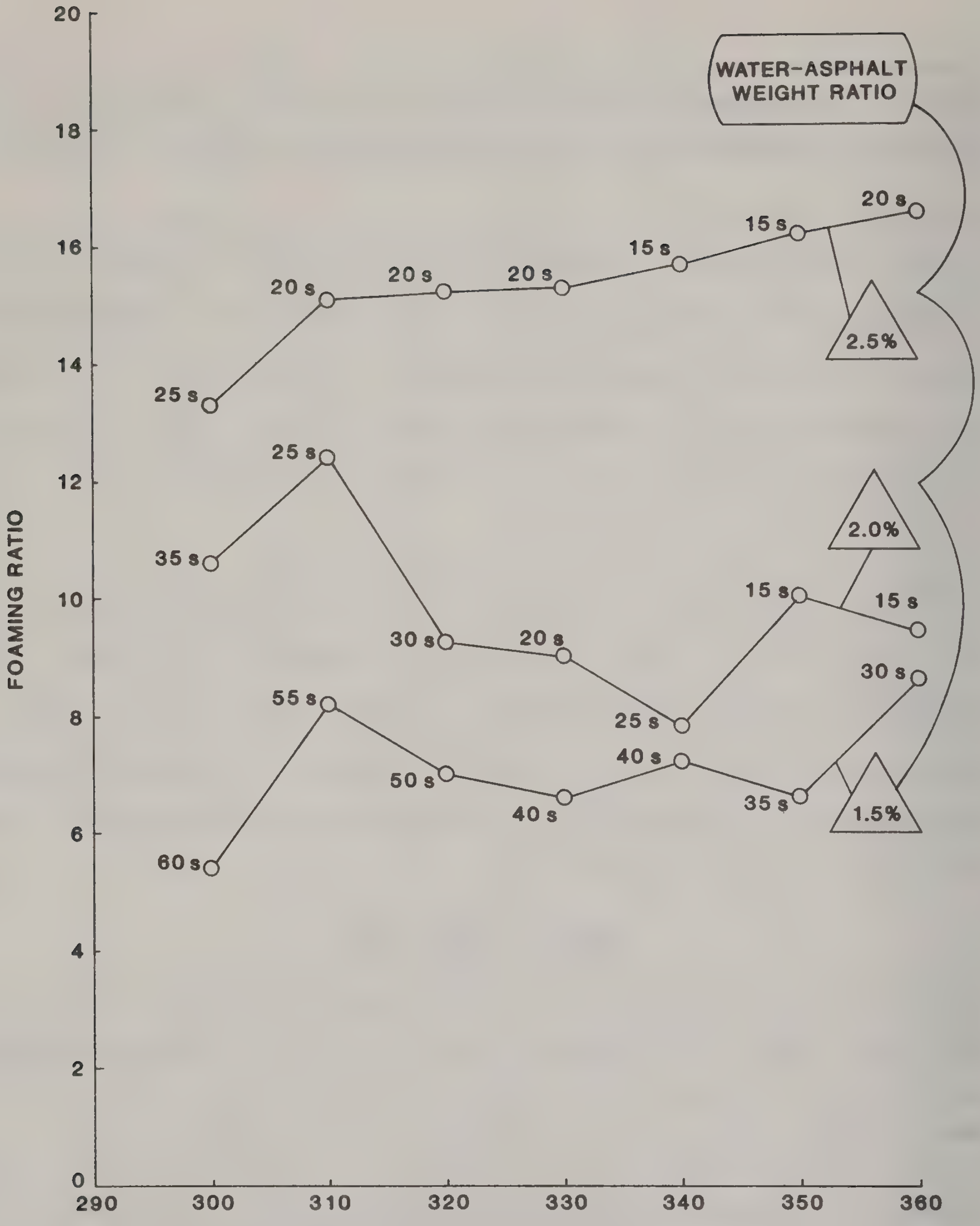


Figure 3. Foaming ratio and half-life as a function of asphalt temperature and water-asphalt weight ratio.

s = half-life, seconds

A harder Cenex asphalt (85/100 penetration) was tested for foaming characteristics. Results of the foaming ratio tests indicate that the harder grade asphalt did not foam as readily as the 120/150 penetration asphalt. Half-lives, however, were approximately equal to those of the 120/150 asphalt (refer to Table 2A).

Two different sources of softer (200/300 penetration) asphalt were tested for foaming ratio and half-life. At a 2.5% water-asphalt weight ratio and an asphalt temperature of 320°F, asphalt from the first source (Cenex) had a foaming ratio of 11 and a half-life of 35 seconds. At a 2.0% water-asphalt weight ratio and an asphalt temperature of 320°F, the foaming ratio of 6.2 was lower than the minimum requirements, but the half-life increased to 60 seconds. At a temperature of 360°F and a water-asphalt weight ratio of 2.0%, the foaming ratio increased to 8.3 (still below minimum), while the half-life decreased to 20 seconds, the very lowest value acceptable under the special provisions.

The second source (Conoco) of 200/300 penetration grade asphalt had low foaming ratios at all the test temperatures. Since the presence of silicone was suspected in the asphalt, 0.45% anti-foam counteractant (Foamaid[5]) was added directly into the asphalt dispenser. The treated asphalt was then circulated for approximately one hour before testing. No significant improvement in the foaming ratio was achieved at any test temperature. A second dosage of Foamaid (0.45%) was added to the same batch of asphalt. This created a circulation problem through the outlet valve of the holding reservoir. Therefore, the dispenser was flushed out and Foamaid was added separately to individual quarts of virgin 200/300 penetration grade asphalt before pouring the asphalt into the dispenser. Each quart of asphalt was vigorously shaken (by hand) with the Foamaid added. Based on these changes, the foaming ratio increased from a high of 6.0 without Foamaid to a high of 9.5 with Foamaid. Half-life also increased from 30 seconds to approximately two minutes. This clearly demonstrates the need for thorough mixing of counteractant and asphalt when counteractant is required.

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[5] Foamaid is a trademark of CONOCO INC.

TABLE 2A

ASPHALT FOAMING RATIO AND HALF-LIFE

Temp. °F	H_2O/ Asphalt %	Foaming Ratio	Half-Life (Secs.)	Temp. °F	H_2O/ Asphalt %	Foaming Ratio	Half-Life (Secs.)
Cenex 120/150				Cenex 120/150			
300	1.5	5.2	60	300	2.0	10.6	35
310	1.5	8.2	55	310	2.0	12.5	25
320	1.5	7.0	50	320	2.0	9.2	30
330	1.5	6.7	40	330	2.0	9.1	20
340	1.5	7.3	40	340	2.0	7.8	25
350	1.5	6.7	35	350	2.0	10.0	15
360	1.5	8.75	30	360	2.0	15.0	15
Cenex 120/150				Cenex 85/100			
300	2.5	12.0	25	320	1.5	3.0	60
310	2.5	13.3	20	340	1.5	4.5	45
320	2.5	15.0	20	360	1.5	6.4	40
330	2.5	16.0	20	320	2.0	4.85	60
340	2.5	16.5	15	340	2.0	5.3	30
350	2.5	16.0	15	360	2.0	9.8	20
360	2.5	15.0	20	320	2.5	12.4	30
				340	2.5	14.3	30
				360	2.5	15.0	25
Conoco 120/150				Conoco 120/150 w/Foamaid			
310	2.5	5	30	310	2.5	7.3	18
335	2.5	5	38	325	2.5	7.8	13
355	4.0	6.8	8	355	2.5	7.0	16

TABLE 2B

ASPHALT FOAMING RATIO AND HALF-LIFE TEST RESULTS

Temp. °F	H_2O/ Asphalt %	Foaming Ratio	Half-Life (Secs.)	Temp. °F	H_2O/ Asphalt %	Foaming Ratio	Half-Life (Secs.)
200/300 Cenex				200/300 Cenex			
300	1.5	4.0	90	300	2.0	5.0	60
320	1.5	4.5	90	320	2.0	6.2	60
340	1.5	5.5	70	340	2.0	7.5	40
360	1.5	5.5	75	360	2.0	8.3	20
Cenex				200/300 Conoco			
300	2.5	8.0	50	300	1.5	3.0	120+
320	2.5	11.0	35	320	1.5	3.3	120+
340	2.5	11.0	30	340	1.5	3.4	100
360	2.5	12.3	30	360	1.5	3.0	100
Conoco				Conoco			
300	2.0	3.0	120	300	2.5	5.4	45
320	2.0	3.2	120	320	2.5	6.0	30
340	2.0	4.0	60	340	2.5	5.8	30
360	2.0	4.0	60	360	2.5	6.0	30
200/300 Conoco w/Foamaid				Conoco w/Foamaid			
300	2.0	6.4	120+	300	2.5	7.7	120+
320	2.0	7.0	120+	320	2.5	8.0	120+
340	2.0	7.0	100	340	2.5	9.1	120
360	2.0	5.0	100	360	2.5	9.5	120
				320	3.0	9.5	100

Results of foaming tests (refer to Tables 2A and 2B) revealed that higher asphalt temperatures produce higher expansion ratios but decrease the half-life. An increase in the water-asphalt weight ratio will likewise increase the foaming ratio and decrease the half-life. Most asphalts tested were capable of meeting special provision requirements if proper temperature, water-asphalt ratios, and/or foaming agents were used.

FREEZE-THAW TEST RESULTS

Freeze-thaw tests (freeze in air;/thaw in water; repeat) were performed on various samples of Foamix. The results of the testing indicate that the softer the asphalt the greater the resistance to repeated freeze-thaw cycling. Also, the degree of curing affects the freeze-thaw resistance of Foamix since specimens oven cured three days at 96°F had test results slightly better than specimens air cured three days at room temperature (73°±) and the test results indicated significant improvement over specimens that were not cured in air at all (refer to Table 3).

A few specimens were thawed in air at room temperature for one to two hours in place of the 30-minute 55°F water thawing process. All of these specimens withstood 60 freeze-thaw cycles with minimal damage; except one made with 5.0% Cenex 85/100 pen. grade asphalt which cracked severely. Overall, specimens with the most freeze-thaw resistance were those which had the higher asphalt contents.

All freeze-thaw specimens were made at the 90% of optimum moisture level unless otherwise noted.

TABLE 3
FREEZE-THAW TEST RESULTS

Sample No.	Asphalt Content (%)	Asphalt Pen.	Cure Period	Thawing Medium	No. of Cycles Before Failure	
567484 (6)	3.75	85/100	3 day 96°F	55°F water	5	
567484 (1)	5.0	85/100	Non-cured	55°F water	3	
567484 (3)	5.0	85/100	3 day 96°F	55°F water	18	
567484 (4)	5.5	85/100	3 day 96°F	55°F water	18	
567484 (5)	5.6	85/100	3 day 96°F	55°F water	23	
567484 2b	4.1	120/150	3 day 96°F	55°F water	5	
567484 A	4.6	120/150	3 day room temp.	55°F water	6	
567484 A	4.6	120/150	3 day 96°F	55°F water	6	
567484 C	5.2	120/150	Non-cured	55°F water	7	
567484 C	5.2	120/150	3 day room temp.	55°F water	12	
567484 C	5.2	120/150	3 day 96°F	55°F water	14	
567484 B	5.8	120/150	3 day room temp.	55°F water	16	
567484 B	5.8	120/150	3 day 96°F	55°F water	20	
567484 IV	4.0	200/300	3 day 96°F	55°F water	22	
567484 IX	4.75	200/300	3 day 96°F	55°F water	30	
567484 V	5.0	200/300	3 day 96°F	55°F water	27	80% OMC
567484 III	5.5	200/300	3 day 96°F	55°F water	34	
567484 XI	5.625	200/300	3 day 96°F	55°F water	34	
567484 (1)	5.0	85/100	Non-cured	Air (room temp.)	After 60 cycles, specimen was cracked	
567484 A	4.6	120/150	3 day room temp.	Air (room temp.)	No damage after 60 cycles	
567484 A	4.6	120/150	3 day 96°F	Air (room temp.)	No damage after 60 cycles	
567484 C	5.2	120/150	Non-cured	Air (room temp.)	No damage after 60 cycles	
567484 C	5.2	120/150	3 day room temp.	Air (room temp.)	No damage after 60 cycles	
567484 B	5.8	120/150	3 day room temp.	Air (room temp.)	No damage after 60 cycles	
567484 B	5.8	120/150	3 day 96°F	Air (room temp.)	No damage after 60 cycles	

RESILIENT MODULUS TEST RESULTS

A non-destructive test known as resilient modulus was also used for Foamix evaluation. Testing involves measuring the amount of deformation in the briquet resulting from application of a pulsating load. The resilient modulus (M_R) is calculated by the following equation:

$$M_R = \frac{P\,(v + 0.2734)}{t\,\Delta}$$

Δ - Horizontal Deformation
P - Vertical Load
t - Specimen Thickness, and
v - Poisons Ratio

The majority of the Foamix resilient modulus testing was of mix made with 120/150 asphalt. Table 4 indicates that curing has a tremendous influence on the resilient modulus results and also that the resilient modulus varies with test temperature (i.e., 57, 73 and 96°F). Specimens that were not cured had a resilient modulus between 5,600 (@ 96°F) to 46,000 psi (@ 55°F). Specimens which were cured for three days in the oven at 96°F had a resilient modulus ranging between 210,000 (@ 96°F) and 720,000 psi (@ 55°F). Note: specimens which were oven cured three days at 120°F (not included in table) had a resilient modulus between 700,000 (@ 73°F) and 1,700,000 psi (@ 55°F).

TABLE 4
AVERAGE RESILIENT MODULUS DATA
AT 55°F, 73°F, AND 96°F TEST TEMPERATURES*

Asphalt Content (%)	55°F Non-Cured (psi)	73°F Non-Cured (psi)	96°F Non-Cured (psi)	55°F Cured (psi)	73°F Cured (psi)	96°F Cured (psi)
3.5	46,191	41,366		718,835	602,103	
4.1	27,250					
4.35	33,676	39,013		494,184	472,675	
4.5	25,748	16,869	11,326	400,374	374,680	328,752
5.1		31,749		463,361		
5.4	31,743	29,957			503,132	
5.5	12,930	7,869	5,602	454,909	284,259	210,244
6.2	31,134	28,400		423,963	395,776	
6.5	11,892	9,625	6,828	428,376	301,669	232,421

* All specimens made with silty sand containing 90% optimum moisture.

Several room temperature air (73°F) cured samples were soaked in water at room temperature for one day and then tested for resilient modulus. Results showed a decrease in the resilient modulus after exposure to the 73°F water. The resilient modulus of specimens with a higher asphalt content did not decrease as drastically as specimens with low asphalt contents (refer to Table 4B). This is probably due to a thicker film of asphalt on the aggregate and/or because there is less interior void space for the water to penetrate.

TABLE 4B

RESILIENT MODULUS OF AIR-CURED SAMPLES SOAKED FOR ONE DAY IN WATER

Asphalt Content (%)	Resilient Modulus (psi)	1 Day Water Exposed Resilient Modulus (psi)
4.0	491,601	242,822
4.75	436,155	248,608
5.3	320,580	211,667
5.8	308,105	207,800

Resilient modulus decreased for samples with an increasing asphalt content for all test temperatures and curing conditions (refer to Figures 4A and 4B). Resilient modulus was higher at a low temperature (55°F) than at warmer test temperatures of 73° and 96°F.

A non-cured specimen containing 5.0% Cenex 85/100 penetration grade asphalt was tested at 73°F. Average M_R was 31,055 psi; which compares to 31,749 psi for the same material mixed with 5.1% Cenex 120/150 asphalt. For comparison, the resilient modulus of mix containing Cenex 200/300 penetration grade asphalt was tested at 73°F. Two cured specimens had results comparable to mix made with the 120/150 asphalt. The results are as follows:

M_R of 3.8% 200/300 Mix = 661,859 psi
M_R of 3.5% 120/150 Mix = 602,103 psi

M_R of 4.75% 200/300 Mix = 400,288 psi
M_R of 4.35% 120/150 Mix = 472,675 psi

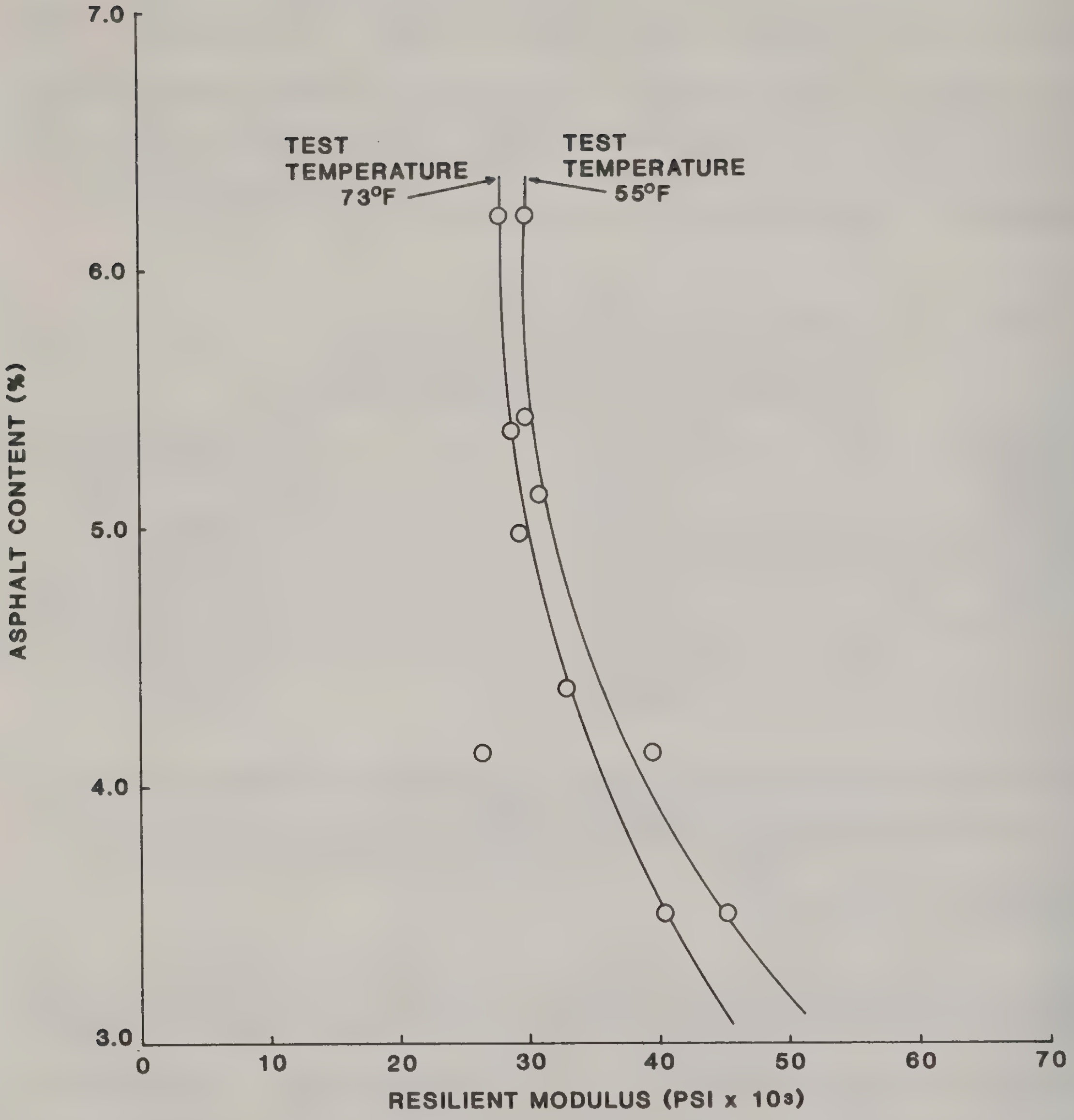

Figure 4A. Asphalt content vs resilient modulus. All specimens made with 90% of optimum moisture and Cenex 120/150 penetration grade asphalt. Tests were of non-cured specimens.

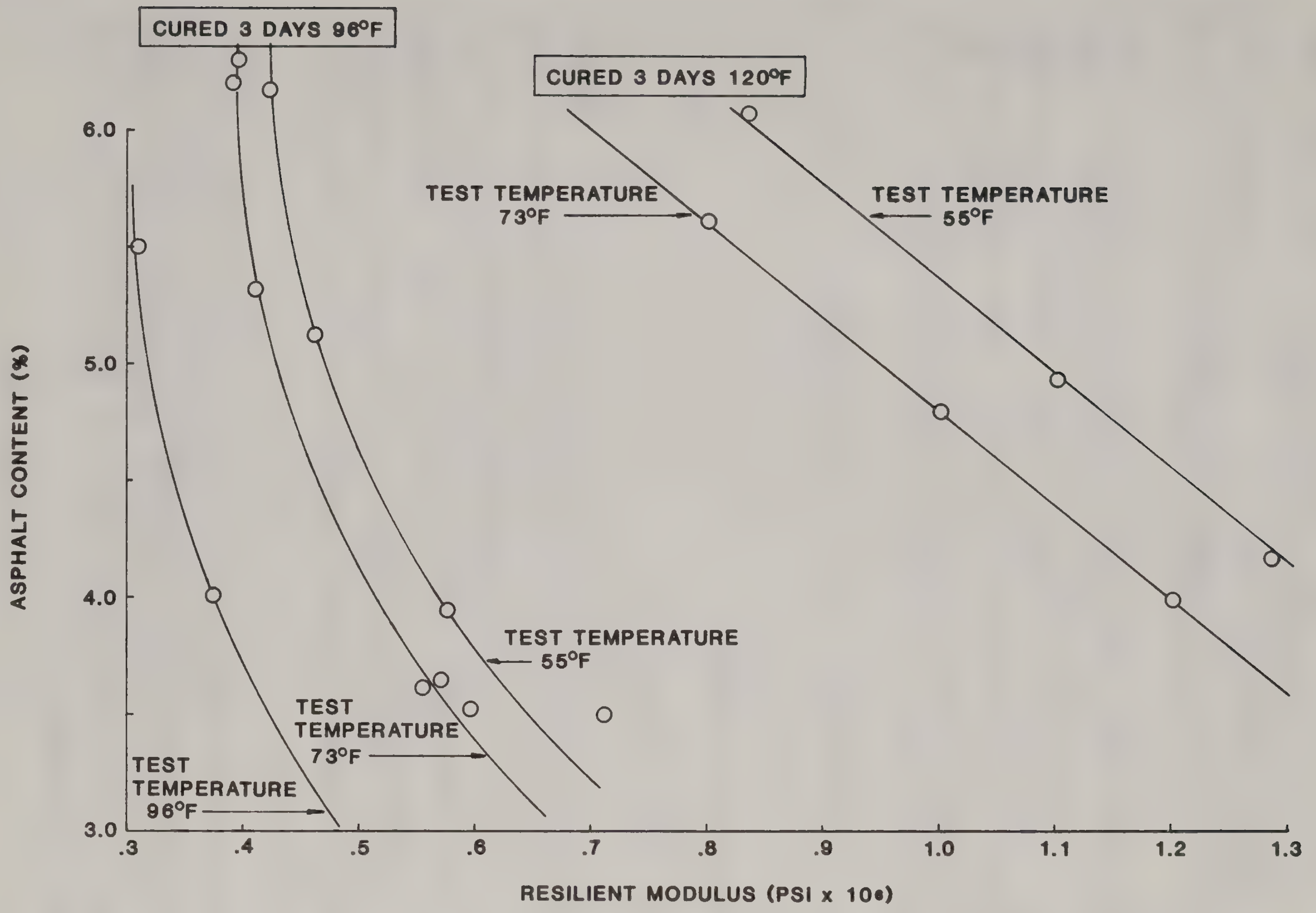

Figure 4B. Asphalt content vs resilient modulus. All specimens made with 90% of optimum moisture and Cenex 120/150 penetration grade asphalt. Tests were of cured specimens.

Extensive M_R research of Foamix containing an 85/100 or 200/300 penetration grade asphalt was not studied; but from the tests performed, it would appear there is no significant difference in the M_R of Foamix specimens made with different grades of asphalt.

INDIRECT TENSILE TEST RESULTS

The indirect maximum tensile stress test is a mathematical manipulation of the elastic "E" modulus loading system. When the Foamix specimen is loaded between two compression platens (rate of 0.065 inches/min.), the induced tensile forces through the vertical axis are at a maximum when the specimen fails. The developed stresses are limited by flattening but related to the thickness of the disc and the load sustained at the time of failure.

The formula for maximum tensile stress is: $S_t = \frac{S_{10} \text{ x Pmax}}{10{,}000 \text{ x L}}$

S_t = maximum tensile strength
P = maximum load
S_{10} = function of flattening

The indirect maximum tensile stress test results (refer to Table 5) indicate that specimens which were oven cured for three days (96°F) had tensile splits approximately five to seven times greater than specimens which were not cured at all. Test temperatures definitely influenced the maximum stress. The colder the test temperature, the higher the maximum stress. Tensile stress decreased with increasing asphalt content for both cured and non-cured specimens with the difference much more noticeable for the oven-cured specimens (refer to Figure 5).

One specimen was oven-cured three days at an elevated temperature (120°F), rather than at the standard cure temperature of 96°F. As expected, an increase in the maximum tensile strength was obtained with a higher curing temperature. This is another indication of how Foamix strengthening is time and temperature dependent.

TABLE 5

COMPARISON OF MAXIMUM TENSILE STRESS VALUES

Non-Cured Specimens			Cured (3 days 96°F) Specimens		
Asp. Cnt.	Tensile Strength (psi)		Asp. Cnt.	Tensile Strength (psi)	
(%)	@ 73°F	@55°F	(%)	@ 73°F	55°F
3.5	7.9	12.55	3.5	69.6	71.9
4.1	6.71	6.31	4.1	----	----
4.35	----	4.51	4.35	65.8	----
4.7	----	-----	4.7	49.7	74.6
5.1	----	7.2	5.1	57.4	----
5.4	7.95	8.9	5.4	----	----
6.2	7.12	8.33	6.2	47.3	58.5

---- no data

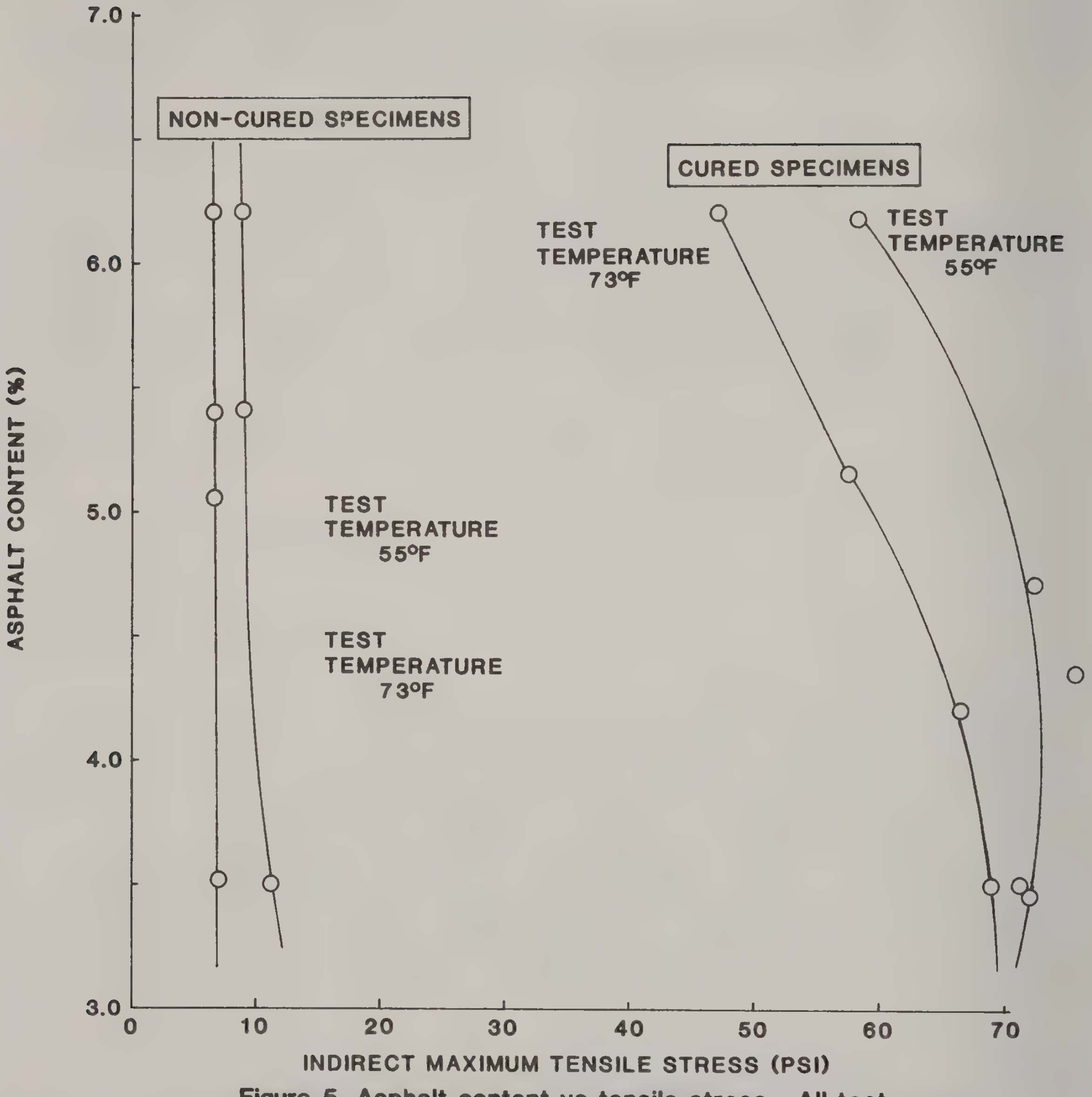

Figure 5. Asphalt content vs tensile stress. All test specimens made with Cenex 120/150 Penetration grade asphalt.

MARSHALL STABILITY AND FLOW TESTING

Marshall stabilities of Foamix made with 120/150 penetration grade asphalt are shown in Figure 6. From the graph it can be shown that stabilities over 1000 pounds were consistently obtained with asphalt contents over 4.5%. This is when the silty sand contained 90% of optimum moisture before mixing. Results were consistently better when the soil contained 90% of optimum moisture as compared to mixes made with 80 and 70% of optimum moisture (refer to Table 1). This was the case for most of the silty sand and all asphalt grades tested.

Stability of Foamix made with 85/100 penetration grade asphalt was much lower than the mix made with softer asphalt. Although this was unexpected, the asphalt did not seem to blend or coalesce with the soil as well as the softer asphalt which is the probable reason for this finding. Stabilities ranged from an average of 220 pounds for Foamix containing 3.75% asphalt to 920 pounds for Foamix containing 5.5% asphalt.

Stability of Foamix made with 200/300 penetration grade asphalt was approximately 2000 pounds for the initial test mixtures containing an asphalt content between 4.0 and 6.0%. Again, stabilities were higher with Marshall specimens made of silty sand containing moisture at 90% of optimum. The stability of compacted silty sand specimens containing 80% of optimum moisture did not change as drastically as that of mixes made with 120/150 or 85/100 penetration asphalt.

A number of specimens were mixed with 5.0 to 5.5% 200/300 penetration grade asphalt and were used to determine the stability of the mix at various moisture contents. Two different curing temperatures, one oven and one air, were used to vary the cure rate. Specimens which cured at 96°F had a faster gain in stability than those cured at 73°F room temperature. A steady increase in stability over time was achieved with both cure temperatures (refer to Figures 7A and 7B). The time required to achieve various stabilities is also shown on the graphs.

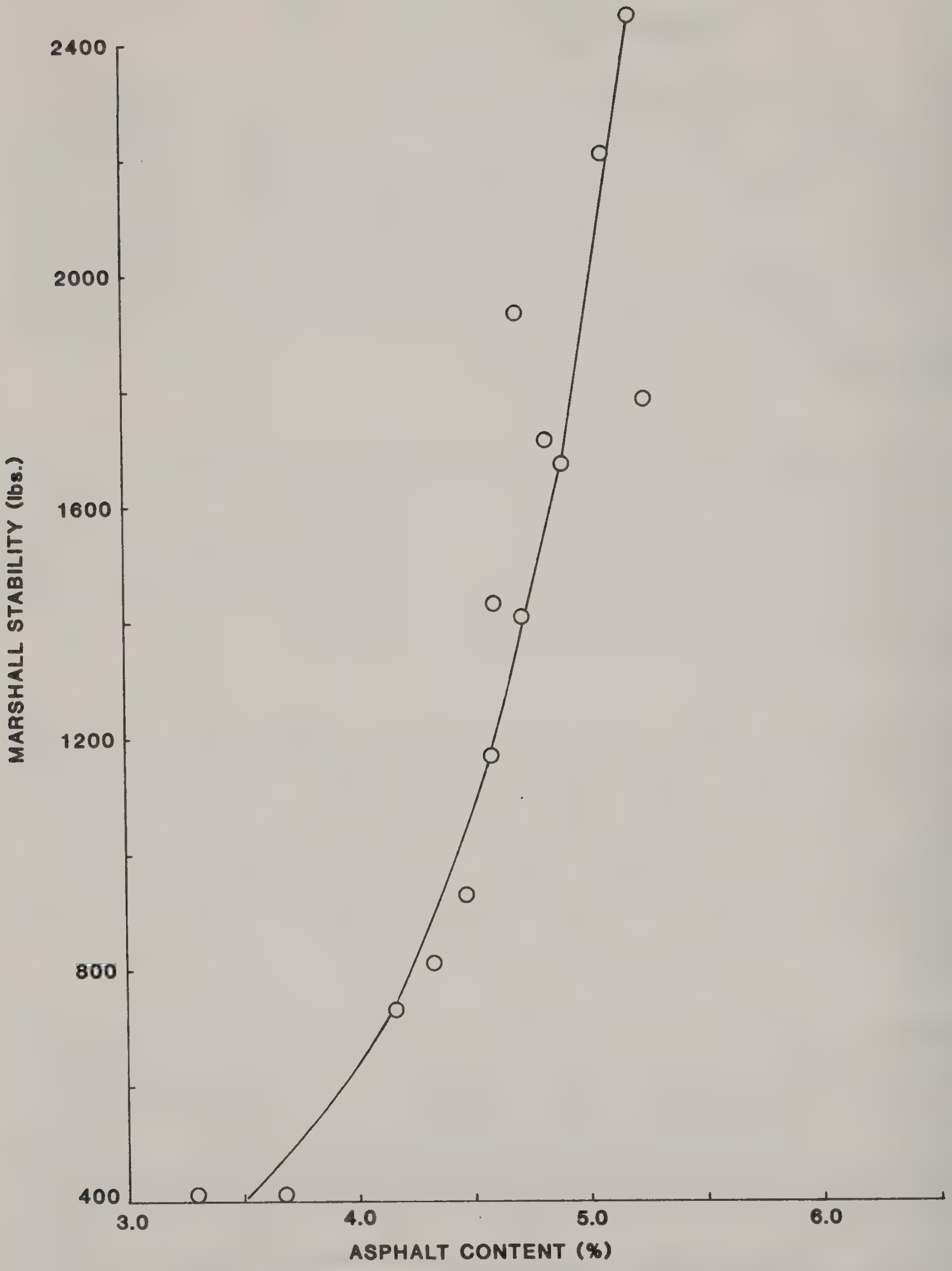

Figure 6. Stability vs asphalt content. All specimens made with 90% of optimum moisture, Conoco 120/150 penetration grade asphalt, and oven cured 3 days at 96°F.

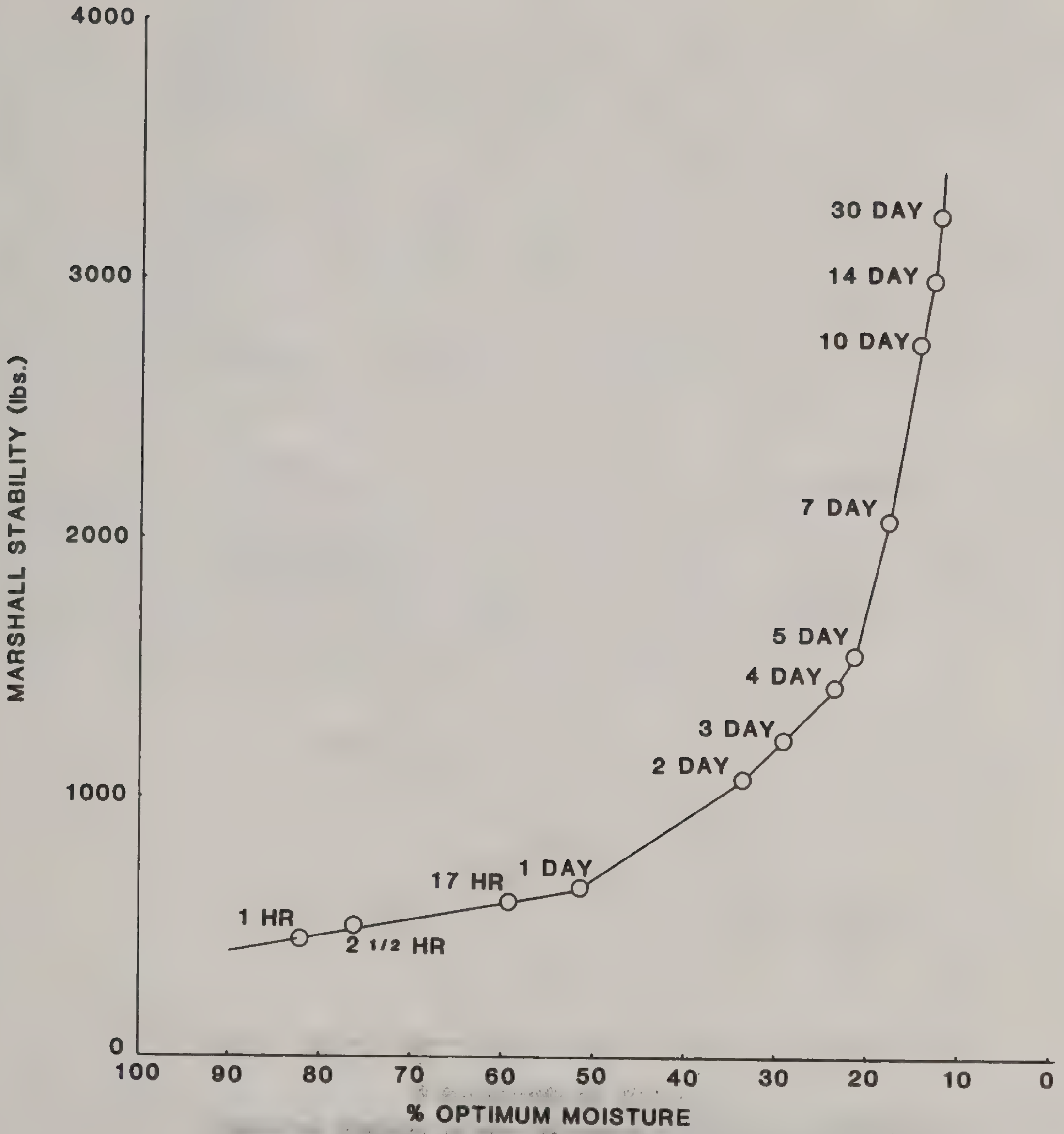

Figure 7A. Stability vs percent moisture. Test specimans constructed with approximately 5.5% Cenex 200/300 penetration grade asphalt and air cured at room temperature.

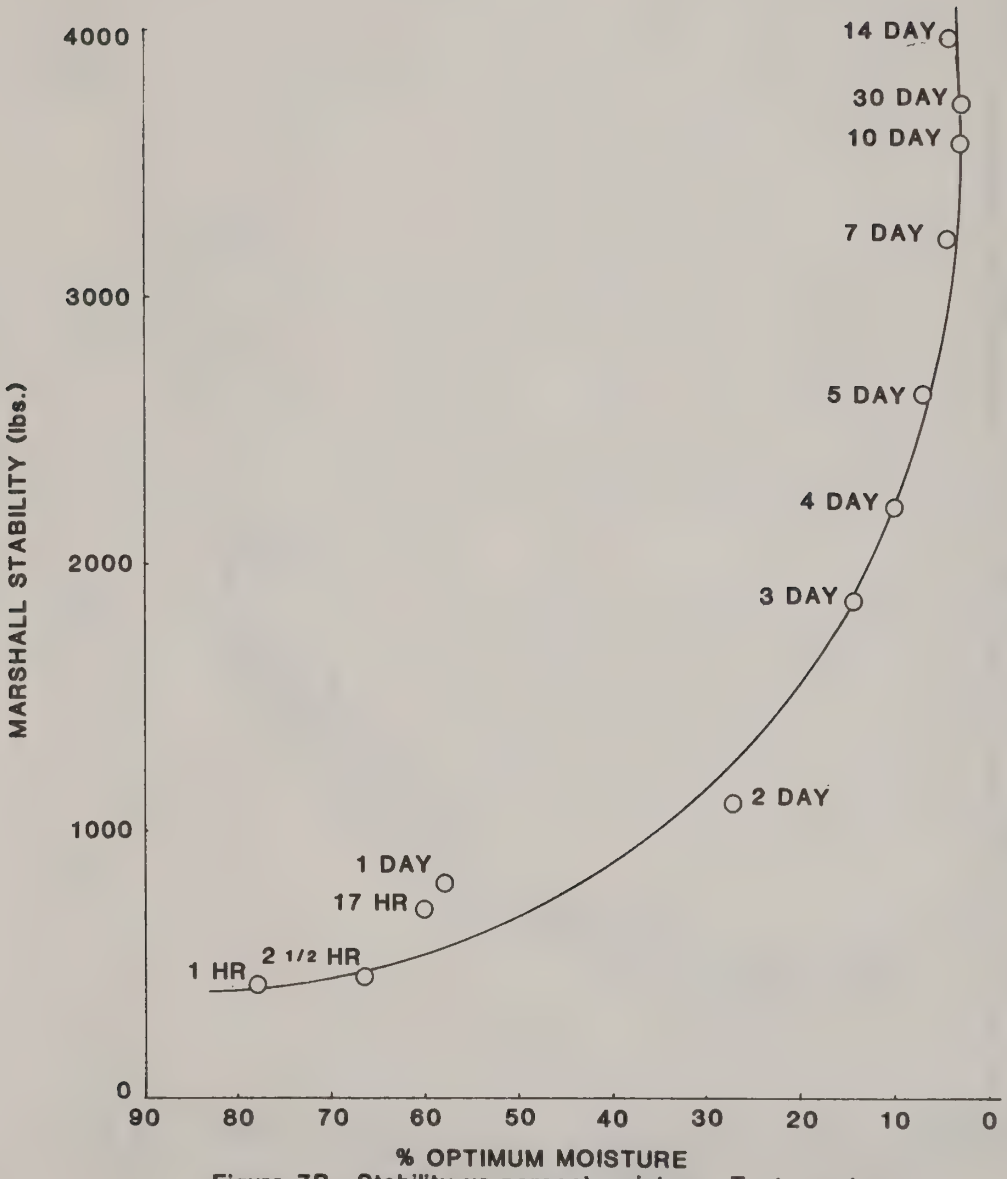

Figure 7B. Stability vs percent moisture. Test specimens constructed with approxmately 5.5% Cenex 200/300 penetration grade asphalt and oven cured at 96 F.

Stability vs. days cured is plotted in Figure 8. This plot is of Foamix made with 4.75% Cenex 200/300 asphalt and silty sand at 90% of optimum moisture. Specimens were oven cured one, two, three, and six days at 96°F. It can be seen that stability increased with time and was higher than the mix made with 5.0-5.5%, Cenex 200/300 pen. grade asphalt.

A graph of stability vs. asphalt content was plotted to determine the optimum asphalt content needed to produce maximum stabilities. Foamix was made with 90% of optimum moisture and Cenex 200/300 penetration asphalt. Since an asphalt temperature of 320°F gave adequate foaming characteristics with a 2.5% water-asphalt weight ratio, these parameters were used for all test mixes. Stability peaked out at approximately 5.0% asphalt (refer to Figure 9) with a value of 2325 pounds and a flow of 0.12 inch. All specimens were cured 3 days at 96°F. Note: stability peaked out at approximately 6.0% asphalt for the three project mix designs which will be discussed later on.

For Cenex and Conoco asphalts, the stabilities of mixes made with 200/300 penetration asphalt were approximately equal to mixes made of 120/150 penetration asphalt when the silty sand contained 90% of optimum moisture. With 80% of optimum moisture, mixes made with 200/300 penetration asphalt had higher stabilities than those with 120/150 asphalt.

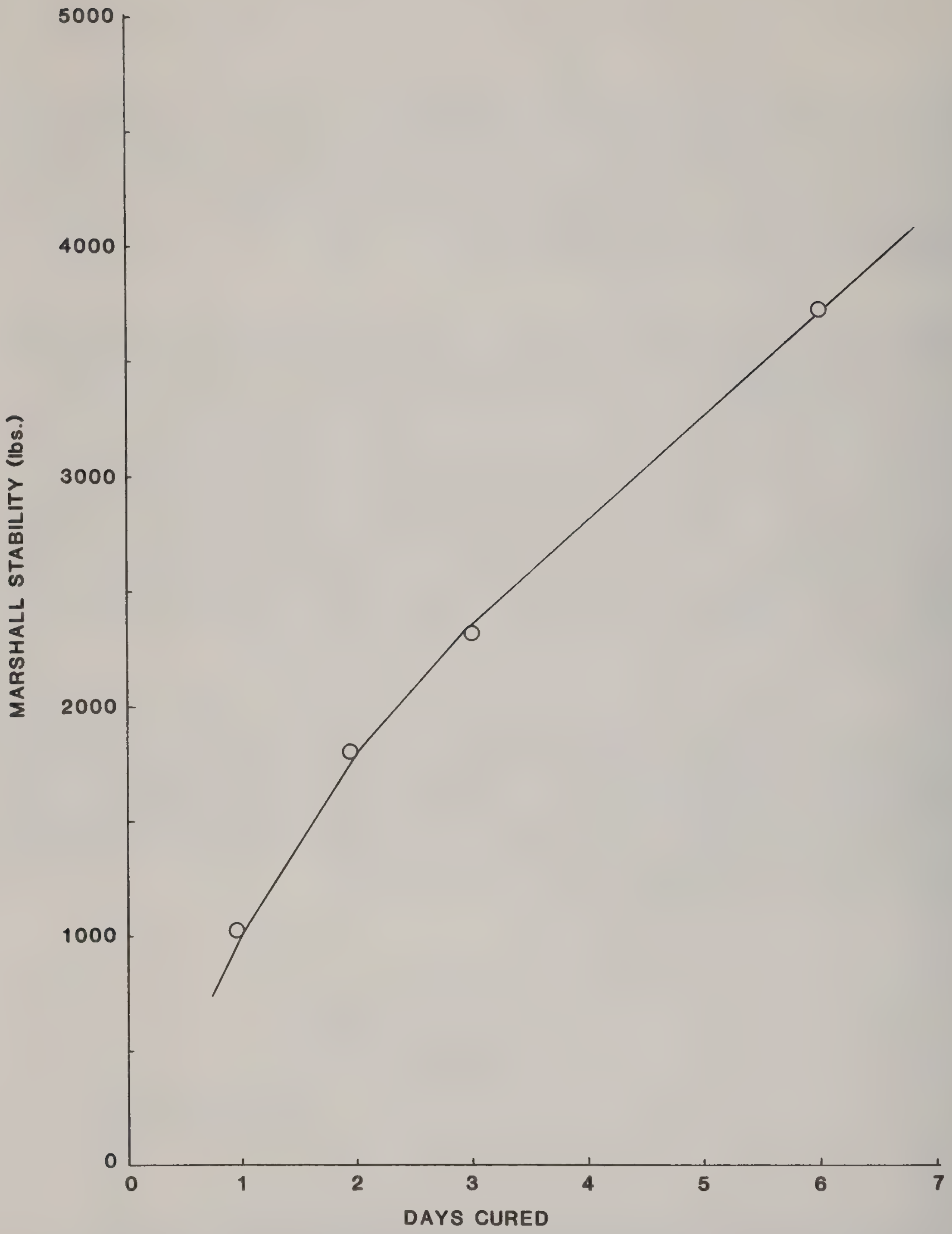

Figure 8. Stability vs cure period. All tests specimens made with approximately 4.75% Cenex 200/300 penetration grade asphalt and oven cured at 96°F.

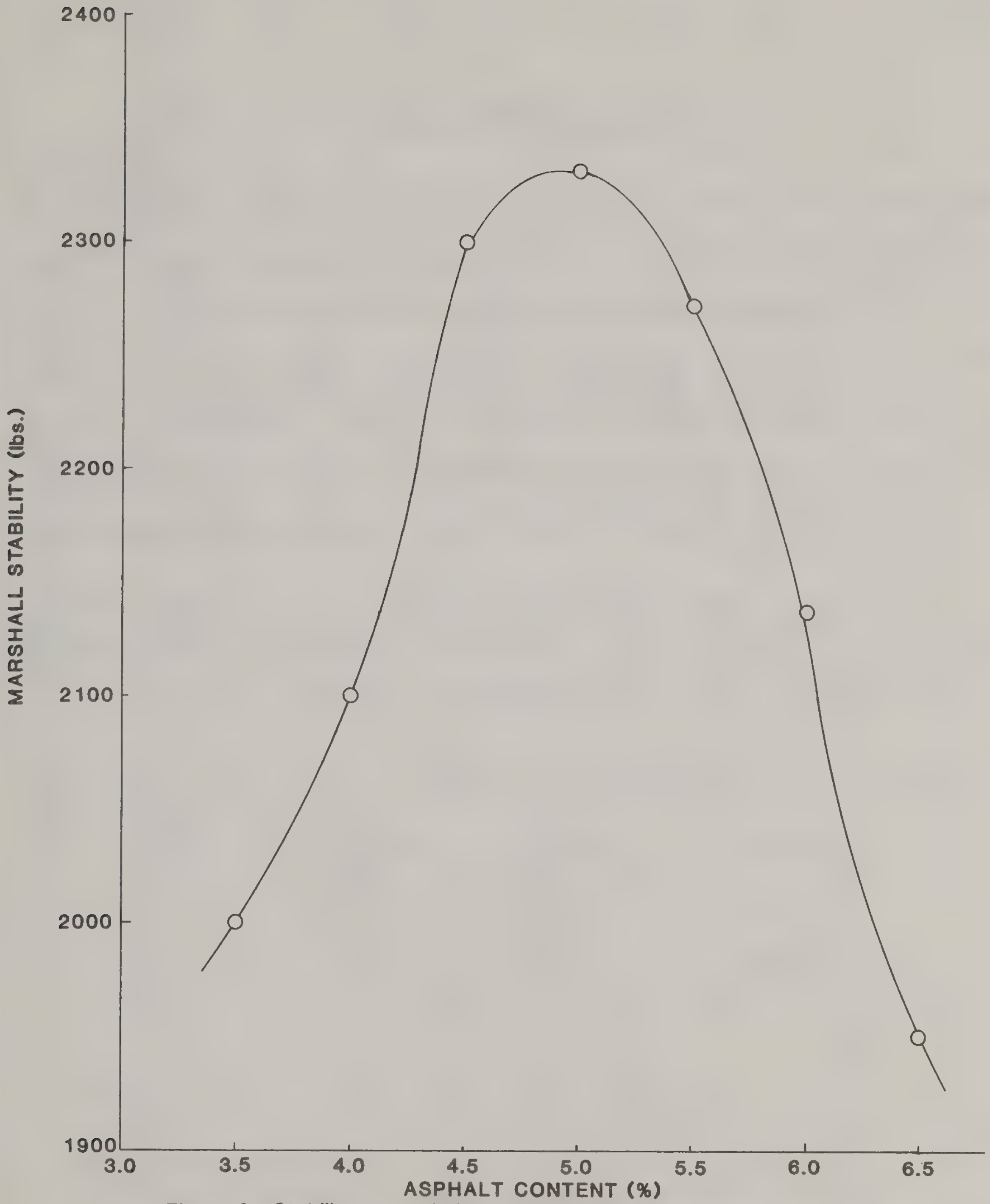

Figure 9. Stability vs asphalt content. All test specimens made with 320°F Cenex 200/300 penetration grade asphalt and oven cured 3 days at 96°F.

WATER ABSORPTION RESULTS

Water absorption of compacted Marshall specimens was monitored at the end of the first hour, the end of the first full day, and finally after four-days. The same specimens were also used to calculate bulk specific gravity. Specimens made with 200/300 penetration asphalt had much lower absorption than mixes made with 120/150 or 85/100 penetration asphalt. The 200/300 penetration mixes were in very good condition after four days of absorption; therefore, they were tested for retained stability. A tabulation of results is listed in Tables 6A and 6B. Although not included in the tables, Exxon 120/150 penetration grade asphalt was used in later testing and found to produce low absorption Foamix capable of being tested for retained stability.

An example of the different absorption percentages of mixes made with different grades of asphalt at the same asphalt temperature, asphalt content, water-asphalt ratio, and moisture content is as follows:

320°F, 5.5% AC, 2.5% H_2O/Asphalt, 90% of OMC

Absorption	85/100	120/150	200/300
1 Hour	6.23%	3.0%	0.88%
1 Day	13.54%	7.54%	2.72%
4 Days	13.95%	9.9%	4.84%

TABLE 6A
CONOCO
RESULTS WITH 200/300 PENETRATION ASPHALT

Lab No. 567484	Cure (Days)	Target Asphalt Content (%)	Calculated Asphalt Content (%)	Absorption			Asphalt Temp. (°F)	% H_2O/ Asp.	Bulk Sp. Gr.	Stability (lbs.)	Flow (.01 in.)	After 30 mins., in 140° bath		Percent Stability Retained (%)
				1 Hour	1 Day (%)	4 Days						Retained Flow (.01 in.)	Retained Stability (lbs.)	
#9	3	3.5	3.75	1.33	3.66	6.1	320	3.0	1.83	2475 2225 2350 avg.	10 10 10	14	670	28.5
#5	4 2/3	4.0	4.4	1.4	4.31	6.27	320	3.0	1.83	3000 2975 2987 avg.	9 9 9	16	700	23.43
#1	3	5.0	4.9	0.64	2.43	3.67	320	3.0	1.85	2500 2250 2325 avg.	12 13 12.5	13	1000	43.0
#7	3 2/3	5.0	5.0	0.68	2.47	4.32	350	3.0	1.87	2775 2520 2647 avg.	10 11 10.5	16	800	30.2
#3	3	5.5	5.2	0.61	2.23	3.34	320	2.5	1.87	1625	13	13	820	50.5
#8	3	5.5	5.6	0.78	2.86	3.70	320	3.0	1.84	1880 1900 1890 avg.	11 11 11	12	780	41.3
#2	3	6.0	5.7	0.63	2.22	3.3	320	2.5	1.85	1910 1900 1905 avg.	10 11 10.5	14	795	41.7
#4	4 2/3	7.0	6.8	0.62	2.20	3.31	320	2.5	1.84	2350 2375 2362 avg.	13 11 12	13	900	38.1
#6	3	8.0	6.9	0.46	1.74	3.34	320	2.5	1.85	1740 1650 1695 avg.	10 10 10	14	700	41.3

NOTE: All silty-sands contained 90% of optimum moisture content.

TABLE 6B
CENEX
RESULTS WITH 200/300 PENETRATION ASPHALT

Lab No.	Cure (Days)	Target Asphalt Content (%)	Calculated Asphalt Content (%)	Absorption (%)			Asphalt Temp. (°F)	% H_2O/ Asp.	Bulk Sp. Gr.	Stability (lbs.)	Flow (.01 in.)	Directly out of 77°F water bath		Percent Stability Retained (%)
				1 Hour	1 Day	4 Days						Retained Flow (.01 in.)	Retained Stability (lbs.)	
I	3	4.5	4.0	1.46	4.10	6.4	320	2.5	1.84	2375	18	12	1360	57.3
IV	3	4.0	4.0	2.2	5.9	8.6	320	2.5	1.84	2100	12	33	900	42.8
VIII	3	4.5	4.6	1.1	2.5	5.1	320	2.5	1.88	----	--	--	---	----
II	3	5.0	4.75	---	---	---	320	2.5	----	2325	13	--	---	----
IX	3	4.5	4.75	1.34	3.69	5.3	320	2.5	1.85	2000	17	30	1540	77.0
III	3	6.0	5.5	0.88	2.7	4.8	320	2.5	1.85	2140	10	24	1620	75.7
XI	3	6.0	5.6	1.27	3.35	5.2	320	2.5	1.88	2000	12	26	1800	90.0

NOTE: All silty sands contained 90% of optimum moisture content.

CONCLUSIONS (for PART I DESIGN)

(1) The percent of moisture in the silty sand prior to adding foamed asphalt is the most important factor in the foamed asphalt mix design. The correct moisture content is critical since the foamed asphalt will not coalesce with the cold moist soil particles if the soil is too damp. With excess moisture, the material would be too sticky to feed through a lay down machine. If the silty sand is too dry, the asphalt tends to disperse sporadically within the mix creating an inadequately bonded material. Thus, the Foamix would be unable to resist moisture penetration and would be prone to ravel when exposed to moisture.

(2) Foamix susceptibility to moisture damage is directly related to time, temperature and a combination thereof (i.e. curing conditions) before being subjected to water. Although no curing is required before compaction, Foamix needs adequate curing following compaction to improve coating and strength characteristics.

(3) Resilient modulus decreases with increasing temperature and decreases rapidly when the compacted specimens are submerged in water. The submerged specimens that contained lower asphalt contents had a greater decrease in resilient modulus than the submerged specimens containing higher asphalt contents. This is another indication that Foamix is susceptible to moisture damage when a low asphalt content is used.

(4) The percentage of water absorbed by compacted specimens decreased with increasing percentages of asphalt in the mix. Absorption also decreased with use of 200/300 penetration grade asphalt when compared to 120/150 and 85/100 penetration grade asphalt. In addition, the stabilities of the mix made with 200/300 penetration asphalt were nearly equal to stabilities of the mix made with 120/150 penetration asphalt. Since moisture susceptibility of Foamix is critical, the softer asphalt should therefore be favored.

(5) The type of mixing equipment, and the method of mixing, greatly affects the Foamix test results. Inadequate results were obtained using a looped-wire whip mixing paddle. With the use of a large, flat mixing

paddle, Foamix performance characteristics improved dramatically. This emphasizes the need for effective mixing equipment for field Foamix production.

(6) The results of the tensile stress and resilient modulus tests indicate peak performance at much lower asphalt contents than the absorption and Marshall stability tests. Since Foamix becomes more and more moisture susceptible at lower asphalt contents, adherence to the higher values of tensile stress and resilient modulus as design parameters could be deceiving, and detrimental, to the overall durability of the mix. Therefore, resilient modulus and tensile stress should be regarded as tests of secondary value in determining the properties of Foamix, they should not be used as primary design criterion.

(7) The water-asphalt weight ratio and asphalt temperature during the foaming operation are important in establishing the foaming ratio and half-life of an asphalt. A higher water-asphalt weight ratio increases the foaming ratio but decreases the half-life. Likewise, a higher asphalt temperature increases the foaming ratio, but again decreases the half-life. Since a high foaming ratio and adequate half-life were obtained for most asphalts tested at 320-330°F and a 2.5% water-asphalt weight ratio, and slightly better test results occurred at these settings, these conditions were adopted as standard design parameters.

FINAL MIX DESIGN RECOMMENDATIONS

The final mix design recommendations for the three experimental projects were based on Marshall stability, Marshall flow, bulk specific gravity, wet density, water absorption, retained stability, and asphalt foaming characteristics. The first mix design which was for the ID 90-9(36)531 U-2, Lodge Grass South project included resilient modulus and indirect tensile split tests. However, due to a lack of time, and also since the stability test is felt to be sufficient for strength evaluation, the resilient modulus and indirect tensile split tests were not conducted for the ID 90-9(62)543, Wyola-South and ID 90-9(38)549 U-2, Wyoming Line North Foamix Base projects.

The silty sand properties used for the mix design of the three projects are listed in the following table. Also, the asphalt characteristics and the mix designs that were used on the projects are listed. Because the Wyola-South and Wyoming Line North projects were constructed from the same pit, they have the same material properties. This particular silty sand had properties similar to that of the majority of silty sand used for the Foamed Asphalt research. However, this sand consisted of very clean rounded particles and had a different appearance and texture than that of the Lodge Grass South silty sand (grey as compared to brown). The test results of Foamix made with this sand were less favorable than that of Foamix made with the "brown" sand but since this sand met all our special provision requirements it was accepted as a Foamix base pit source. The smoother rounded particles do not interlock as well as the more angular material contained in the Lodge Grass South silty sand and therefore the Foamix engineering properties were not as good.

SOIL CHARACTERISTICS

	Lodge Grass - South	Wyola-South, Wyoming Line N.
Soil Optimum Moisture Content	16.0%	15.0%
Maximum Density (Wet)	109.7 lbs./ft.^{3}	108.0 lb./ft.^{3}
Liquid Limit	NP	NP
Plastic Limit	NP	NP
Plasticity Index	NP	NP
Soil Classification	A-2-4(0)	A-2-4(0)
% Passing 4M Sieve	100	*98
% Passing 200M Sieve	17.9	13.2
R-Value	72	69

ASPHALTS

Originally, the asphalt for the three projects was to be supplied by two different asphalt refineries. The Lodge Grass South and Wyola South projects intended on using asphalt from the Conoco refinery while the Wyoming Line North project was to be constructed with asphalt from the Cenex refinery. Therefore, our original testing was with only these asphalt sources. Three different grades of asphalt were tested from each refinery which includes 85/100, 120/150, and 200/300 penetration grade asphalt.

After numerous tests with each asphalt, it was discovered that Conoco's asphalt was not capable of meeting our special provision foaming requirements. Therefore, Cenex and Exxon asphalt was used.

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*Our special provisions require 100% passing the 4M sieve. Therefore, material was screened before it was used for testing. All the requirements of the special provision were met.

Conoco, Inc. did not have a grade of asphalt capable of meeting the 10:1 minimum foaming requirement. This is because their asphalt is refined with a silicone additive which is an anti-foaming agent. Therefore, a counteractant (Foamaid) was added to their asphalt to improve its foaming ratio. The foaming ratio did improve and increased to as high as 9.5:1. Even though the foaming ratio was below the minimum special provision foaming ratio, a number of mixes were tested with Conoco's asphalt and found to produce good laboratory test results with or without Foamaid. However, since producing Foamix in the field had never been done in Montana and since previous Foamix projects in other states recommended high foaming ratios, Conoco's asphalt was not used. Therefore, Conoco requested we try Exxon 120/150 penetration grade asphalt in place of their asphalt. Although we had better overall test results with a softer grade of asphalt (i.e. 200/300 pen.), and Exxon does not produce AC 200/300 in sufficient volumes to supply the required need for an asphalt paving project, we agreed to test the Exxon 120/150 penetration grade asphalt.

The special provision foaming requirements of Exxon 120/150 penetration grade asphalt were acceptable at a wide range of asphalt temperatures and water/asphalt weight ratios. This would be beneficial to field mixing if the asphalt temperature fluctuates from our recommended asphalt mixing temperature. The Exxon foaming results were as follows:

EXXON 120/150 FOAMING CHARACTERISTICS

ASP. TEMP. (°F)	H_2O/ASP. WT. RATIO (%)	FOAMING RATIO	HALF LIFE (SECS.)
310	2.5	14.4	32
320	2.5	11.1	43
320	2.5	11.3	40
330	1.5	5.6	90
330	2.5	13.0	36
335	2.5	13.8	30
350	1.5	5.6	60
350	2.0	11.2	40
350	2.5	16.0	35

Since Exxon's asphalt was capable of meeting the special provision foaming requirements, we proceeded to test Foamix made with Exxon 120/150 penetration grade asphalt. Physical test results of Foamix made with this asphalt revealed that quality Foamix can be produced. Therefore, providing that the Exxon AC 120/150 asphalt met our foaming requirements when it was received in the field, we approved Conoco's request to use Exxon's asphalt as a replacement asphalt for the ID 90-9(36)531 U-2, Lodge Grass South, and ID 90-9(62)543, Wyola-South Foamix Base projects.

The final mix design recommended for the three projects were as follows:

PROJECT MIX DESIGNS

PROJECT	ASP. CNT. (%)	PCT. of OPT.MST. (%)	ASP. TEMP. (°F)	H_2O/ASP. WT.RATIO (%)	ASPHALT
ID 90-9(36)531 U-2 Lodge Grass South	6.0	90.0	330	2.5	Exxon 120/150
ID 90-9(62)543 Wyola-South	6.25	80.0	330	2.5	Exxon 120/150
ID 90-9(38)549 Wyoming Line North	6.25	80.0	330	2.5	Cenex 200/300

Following are the detailed mix design results for each project which were sent by memorandum to the Billings District.

MIX DESIGN RESULTS

MONTANA DEPARTMENT OF HIGHWAYS
Helena, Montana 59620

MEMORANDUM

TO: Duane Meiers, P.E., District Engineer
Billings District

FROM: Richard E. Wegner, P.E. Chief
Materials Bureau

Richard E Wegn

RE: ID 90-9(36)531 U-2

DESIGNATION: Lodge Grass - South

LAB. NO.: 576409

DATE: November 19, 1984

For your information, attached please find the detailed mix design results of Foamix base for the Lodge Grass - South (Empire Sand and Gravel) project.

RTR:MM:sk:4a

cc: Don Kittelson
Ken Neumiller
Robert Rask
Mark Mullaney

The tests performed for the design of Foamix Base for Lodgegrass - South include Marshall stability and flow, resilient modulus, indirect tensile stress, bulk specific gravity, water absorption, and retained stability. Soil classification, gradation, Atterburg Limits, optimum moisture and maximum density of the soil were determined by the standard AASHTO procedure. Also an R-value of the soil was determined (See Table 1).

Foaming characteristics of three different asphalts were tested at various asphalt temperatures and water/asphalt weight ratios. All three (Table 2) were determined capable of meeting foaming requirements if the proper temperature, water/asphalt weight ratio and addition of Foamaid was used if necessary. Only one of the three asphalts tested required Foamaid.

Since the foaming ratio was higher with a greater water/asphalt weight ratio and the half-life was at least the required minimum of 20 seconds, design of Foamix was made with a 2.5% water/asphalt weight ratio at the middle of the allowed asphalt temperature range of 300 to 360°F. This was used for design with all three asphalts.

TABLE 1 SOIL CHARACTERISTICS

Lab No. 576409

Soil Optimum Moisture Content	16%
Maximum Density	109.7 lbs./ft.^{3}
Liquid Limit	NP
Plastic Limit	NP
Plasticity Index	NP
Soil Classification	A-2-4(0)
% Passing 4M Sieve	100
% Passing 200M Sieve	17.9
R-Value	72

TABLE 2 - FOAMING CHARACTERISTICS

Exxon 120/150

Asphalt Temp. (°F)	H_2O/Asphalt Wt. Ratio (%)	Foaming Ratio	Half-Life (Secs.)
310	2.5	14.4	32
320	2.5	11.1	43
320	2.5	11.3	40
330	1.5	5.6	90
330	2.5	13.0	36
335	2.5	13.8	30
350	1.5	5.6	60
350	2.0	11.2	40
350	2.5	16.0	35

Cenex 200/300

Asphalt Temp. (°F)	H_2O/Asphalt Wt. Ratio (%)	Foaming Ratio	Half-Life (Secs.)
300	1.5	4.0	90
320	1.5	4.5	90
340	1.5	5.5	70
300	2.0	5.0	60
320	2.0	7.5	40
340	2.0	8.3	25
300	2.5	8.0	50
320	2.5	11.1	35
320	2.5	10.8	35
340	2.5	11.0	30
350	2.5	12.3	30

Conoco 200/300 With Foamaid

Asphalt Temp. (°F)	H_2O/Asphalt Wt. Ratio (%)	Foaming Ratio	Half-Life (Secs.)
300	2.0	6.4	120+
320	2.0	7.0	120+
340	2.0	7.0	100
360	2.0	5.0	100
300	2.5	7.7	120+
320	2.5	8.0	120+
340	2.5	9.1	120
360	2.5	9.5	120

Cured (@ 3 days 96°F) and non-cured samples of Foamix made with Exxon 120/150 penetration asphalt were tested for resilient modulus, and indirect tensile stress at temperatures of 55, 73, and 96°F. Due to a lack of time, resilient modulus and indirect tensile stress tests were not performed on mixes made with the other two asphalts. Therefore, a comparison of the mixes made with different asphalt cannot be made.

Since Marshall stability, indirect tensile stress, and resilient modulus are all strength related, the stability test was felt to be sufficient for strength evaluation. The results of resilient modulus and indirect tensile stress are listed in Tables 3 and 4. The results of absorption, bulk specific gravity, stability and flow, and retained stability of absorption specimens all made at the mix design asphalt temperature of 330°F and water/asphalt weight ratio of 2.5% are listed in Tables 5 and 6.

Once a mix design was selected, tests using different asphalt temperatures and water/asphalt weight ratios at the designated asphalt and moisture content mix design were performed. Also mixes using soil with high and low percentages of -200 mesh material made at mix design were tested (see Table 7).

TABLE 3 - RESILIENT MODULUS AND TENSILE STRESS OF NON-CURED TEST SPECIMENS

Asphalt Content (%)	Moisture Content (% Optimum)	Average M_R & Tensile Stress	(PSI)	
		55°F	73°F	96°F
4.5	90	25,748	16,869	11,326
		7.6	7.0	6.27
5.5	90	12,930	7,869	5,602
		6.45	5.22	3.85
6.5	90	11,892	9,625	6,828
		6.20	6.11	5.15
5.0	80	17,876	15,019	13,053
		6.5	5.58	5.06
5.5-6.0	80	35,781	23,949	14,855
		7.1	6.17	5.51
6.0	70	40,043	22,934	19,064
		8.81	6.36	5.8

Soil 576409
Exxon 120/150 330°F 2.5% Water/Asphalt

From the above data, the following conclusions can be made:

1) Resilient Modulus decreased with an increased temperature,
2) Resilient Modulus increased with a decreased moisture content,
3) Resilient Modulus decreased with an increased asphalt content at 90% O.M. but increased with an increased asphalt content at 80% O.M.,
4) Tensile stress decreased with an increased temperature, and
5) The highest values of resilient modulus and tensile stress occurred in the driest mixes.

TABLE 4 - RESILIENT MODULUS AND TENSILE STRESS OF CURED TEST SPECIMENS

Asphalt Content (%)	Moisture Content (% Optimum)	Average M_R & Tensile Stress	(PSI)	
		55°F	73°F	96°F
4.5	90	400,374	374,680	328,752
		62.6	59.1	37.0
5.5	90	454,909	284,259	210,244
		68.9	48.2	32.81
6.5	90	428,376	301,669	232,421
		63.4	59.1	
5.0 [1]	80	302,916	319,966	341,005
		65.2	56.9	
5.5-6.0	80	476,874	407,882	259,750
		62.9	49.9	
6.0	70	907,926	445,499	350,604
		69.6	42.9	

Soil 576409
Exxon 120/150 330°F 2.5% Water/Asphalt

The resilient modulus decreased with a increased temperature for all but one mix. A decrease in optimum moisture increased resilient modulus. The maximum tensile stress decreased with an increased temperature.

TABLE 5 - EXXON 120/150

576409

Opt. Mst. Cnt. %	Asp. Cnt. %	Bulk Sp. Gr.	Absorption			Stability Lbs.	Avg.	Flow In.	Retained Stability & Flow Lbs., In.	Comments
			1-Hr %	1-Day %	4 Days %					
90	4.5	1.857	3.61	8.1	9.81	1240, 1260	1250	0.10, 0.10	210, 0.23	119.4 lbs/ft^3 Wet Density
90	5.5	1.865	2.08	5.55	7.1	1420, 1725	1573	0.10, 0.11	365, 0.22	120 lbs/ft^3
90	6-6.5	1.824	0.78	2.52	4.1	1850, 1920	1885	0.10, 0.10	655, 0.15	120.9 lbs/ft^3
80	5.0	1.827	5.21	11.78	12.74	1200, 1275	1237	0.16, 0.15	120, 0.27	116.3 lbs/ft^3
80	5.5-6.0	1.871	2.74	6.43	7.85	1500, 1710	1605	0.11, 0.12	350, 0.25	117.8 lbs/ft^3
70	6.0	1.777	11.1	14.93	15.17	135, 300	217	0.25, 0.22	Disintegrated	111.9 lbs/ft^3
70	5.0	1.787	11.56	15.0	d	125, 110	117	0.25, 0.22	Disintegrated	
90	6.5-7.0	1.856	1.10	2.91	5.23	2160, 2250	2205	0.15, 0.14	660, 0.17	Cured 4 Days
90	6.4-6.5	1.862	1.0	3.3	4.6	2100, 2000	2050	0.12, 0.12	675, 0.17	Cured 3 2/3 Days 1820 lbs @ 3 Days
90	5.7-6.0	1.87	1.48	-----	5.70	1850, 1970	1910	0.13, 0.11	535, 0.16	
90	6.7-7.0	1.87	0.84	-----	4.92	1750, 1720	1735	0.13, 0.12	445, 0.16	

TABLE 6 - CENEX & CONOCO 200/300

Cenex 200/300

Opt. Mst. Cnt. %	Asp. Cnt. %	Bulk Sp. Gr.	Absorption			Stability Lbs.	Avg.	Flow In.	Retained Stability & Flow Lbs., In.	Comments
			1-Hr %	1-Day %	4 Days %					
90	4.5-5.2	1.897	1.01	2.6	4.77	1975, 1925	1950	0.12, 0.11	375, 0.12	
90	5.5-6.0	1.895	0.74	2.2	4.17	1610, 1590	1600	0.12, 0.11	375, 0.12	
90	6.5-7.1	1.890	0.66	1.94	3.80	1640, 1600	1620	0.12, 0.12	325, 0.11	
80	5.0-5.4	1.892	1.41	3.53	5.88	1860, 1650	1755	0.09, 0.10	390, 0.15	
80	6.0-6.6	1.911	0.79	2.2	4.10	1640, 1490	1565	0.10, 0.09	465, 0.13	
Conoco 200/300 With Foamaid										
90	4.5-5.1	1.904	1.02	2.76	5.10	1850, 1975	1913	0.11, 0.13	370, 0.12	
90	5.5-6.0	1.896	0.77	2.26	4.40	1620, 1670	1645	0.12, 0.12	375, 0.12	
90	6.5-7.1	1.876	0.63	1.96	4.1	1430, 1500	1465	0.11, 0.14	375, 0.14	
80	5.0-5.6	1.906	1.50	3.85	6.5	1820, 1750	1785	0.11, 0.11	310, 0.16	
80	6.0-6.8	1.912	1.04	2.60	4.5	1590, 1575	1583	0.11, 0.11	385, 0.12	

TABLE 7 - EXXON 120/150

Opt. Mst. Cnt. %	Asp. Cnt. %	Bulk Sp. Gr.	Absorption 1-Hr %	Absorption 1-Day %	Absorption 4 Days %	Stability Lbs.	Avg.	Flow In.	Retained Stability & Flow Lbs., In.	Comments
90	6.7-6.0		1.06	-----	5.35	1420, 1625	1525	0.13, 0.12	470, 0.16	1.5% H_2O/ASP. Wt. Ratio 310°F ASP.
90	6.0		1.26	-----	5.5	1680, 1810	1745	0.12, 0.11	510, 0.16	1.5% H_2O/ASP. Wt. Ratio 330°F ASP.
90	6.0		1.25	-----	5.2	1680, 1725	1700	0.12, 0.11	495, 0.16	1.5% H_2O/ASP. Wt. Ratio 350°F ASP.
90	6.4-6.0		1.24	3.36	5.0	1675, 1725	1700	0.11, 0.12	505, 0.16	2.5% H_2O/ASP. Wt. Ratio 310°F
90	5.9-6.0		1.49	-----	5.85	1525, 1640	1580	0.11, 0.11	420, 0.15	2.5% H_2O/ASP Wt. Ratio 350°F
90	6.3-6.0	1.66	4.3	8.43	9.76	880, 660	765	0.08, 0.08	175, 0.21	At Mix Design W/ + 4M Mat'l.
90	5.9-6.0	1.75	11.5	d	d	1090, 1080	1085	0.14, 0.16	---------	30.7% -200M Cured 4 Days
90	5.8-6.0	1.71	4.5	-----	11.43	620, 720	670	0.08, 0.12	240, 0.18	13.7% -200M 576775 Soil

Based on the results of water absorption and Marshall stability and flow, a mix design of 90% optimum moisture and 6.0% Exxon 120/150 penetration asphalt is recommended. An asphalt temperature of 330°F and 2.5% water/asphalt weight ratio produced a foaming ratio of 13 and a half-life of 36 seconds.

At a 1.5% water/asphalt weight ratio the foaming ratio did not meet the minimum foaming requirement of 8 at any temperature within the range of 300-360°F. Although the foaming requirements were unacceptable at a 1.5% water/asphalt weight ratio, absorption and Marshall stability of the mix made with a 1.5% water/asphalt weight ratio were comparable to that of mix made with a 2.5% water/asphalt weight ratio. Since field mixing time is less than laboratory mixing time, a higher foaming ratio would probably be more beneficial to the quality of the field mix than the laboratory mix due to a greater initial dispersion of asphalt at a high foaming ratio. Therefore, if field mixtures do not correlate with laboratory mixtures, the laboratory mixing time may need to be shortened to more accurately predict material properties in the field.

Three mixes made at mix design were tested with different soils. The different soils were as follows:

1) No. 576775, 13.7% -200 Mesh
2) No. 558494, 30.7% -200 Mesh
3) No. 575111, +4 Mesh Balls of Silty Sand

All three produced worse results than similar mix made with soil containing 100% passing the 4 mesh sieve and 17.9% passing the 200 mesh sieve. Since an average optimum moisture content will be used on the job, an adjustment for different optimum moisture contents of the three soils was not made. This may have contributed more to the poorer results than the difference in gradation but it also emphasizes the need of quality control in the field.

MM/dk/211x

MONTANA DEPARTMENT OF HIGHWAYS
Helena, Montana 59620

MEMORANDUM

TO: Duane Meiers, P.E.
District Engineer - Billings

FROM: Richard E. Wegner, P.E., Chief
Materials Bureau

Richard E. Wegner

RE: ID 90-9(38)549 U-2

DESIGNATION: Wyoming Line North

LAB NO.: 578885

DATE: December 13, 1984

Attached, please find the Foamix Base mix design results from material in the NE¼ of Section 30, T-8-S, R-36-E, left of centerline approximately 500', Distr. Lab. No. 510-44411-13.

The tests performed for the design of Foamix Base for Wyoming Line North include Marshall stability and flow, bulk specific gravity, water absorption, and retained stability. Soil classification, gradation, Atterburg Limits, optimum moisture and maximum density of the soil were determined by the standard AASHTO procedure. Also an R-value of the soil was determined (See Table 1).

Foaming characteristics of Cenex 120/150 and 200/300 penetration asphalt were tested at various asphalt temperatures and water/asphalt weight ratios. Both asphalts were determined capable of meeting foaming requirements if the proper temperature and water/asphalt weight ratio were used (See Table 2). The 120/150 asphalt produced greater foaming ratios and longer half-life than the 200/300 asphalt.

Since a 2.5% water/asphalt weight ratio and 330°F asphalt temperature produced both an adequate foaming ratio and half-life for both asphalts, these standards were used for design. Once a design was selected, the standards were adjusted to different values to determine their effect in lowering or improving the test results.

For your information, all the test results have been provided. Please refer to the succeeding six tables in regards to the following:

1) Soil Characteristics,
2) Foaming Ratio and Half-Life,
3) Summation of Test Results,
4) Optimum Foamix Results with 200/300 Pen. Asphalt,
5) Optimum Foamix Results with 120/150 Pen. Asphalt, and
6) Comparison of Results by Varying the Asphalt Temperature and Water/Asphalt Weight Ratio with the Optimum Moisture and Asphalt Content Mix Design.

Table 1 - Soil Characteristics

Lab No. 578885

Soil Optimum Moisture Content		15.0%
Maximum Density		108.0 lb./ft.^{3}
Liquid Limit		NP
Plastic Limit		NP
Plasticity Index		NP
Soil Classification		A-2-4(0)
% Passing 4M Sieve	*	98
% Passing 200M Sieve		13.2
R-Value		69

* Our Special Provisions require 100% passing the 4M sieve. Therefore, material was screened before it was used for testing. All the requirements of the special provision were met.

Table 2 - Foaming Ratio and Half-Life of Asphalts Tested

Asphalt	Asphalt Temp. (°F)	H_2O/ASP Wt. Ratio (%)	Foamed Ht. (In.)	Settled Ht. (In.)	Foaming Ratio	Half-Life (Secs.)
CX 120/150	310	2.5	4.875	0.5	9.75	58
CX 120/150	330	2.0	3.3125	0.375	8.8	47
CX 120/150	330	2.5	5.125	0.4375	11.7	28
CX 120/150	350	2.5	4.6875	0.375	12.5	26
CX 120/150	350	1.5	3.000	0.4375	6.9	37
CX 200/300	310	2.5	4.000	0.5	8.0	40
CX 200/300	330	2.0	2.625	0.375	7.0	46
CX 200/300	330	2.5	3.4875	0.375	~~9.3~~ 11.0	32
CX 200/300	340	2.5	3.5625	0.375	~~9.5~~ 11.0	30
CX 200/300	350	2.5	4.000	3.375	10.7	23

Table 3 - Test Results

									Absorption %			RETAINED		
Lab No.	Sample I.D. Letter	Calculated Asp.Cnt. (%)	Target Asp.Cnt. (%)	Asp. Type	Pct. of Opt. Mst.	Avg. Marshall Stability (lbs.)	Avg. Marshall Flow (0.01 in.)	Bulk Sp.gr.	1 Hour	1 Day	4 Days	Stability (lbs)	Flow (.01 in.)	Stability (%)
578885	1	5.3	5.5	EXX 120/150	110	955	7	1.825	1.975	6.1	7.96	255	10	26.7
577885	A	4.3	3.5	CX 200/300	95		FAILED, WOULD NOT COMPACT)-------------------------							
577885	B	5.5	4.5	CX 200/300	95	1000	7	1.84	1.13	---	5.0	390	9	39.0
577885	C	5.7	5.5	CX 200/300	90	1045	6	1.84	1.13	---	5.25	315	12	30.1
577885	D	6.5	6.5	CX 200/300	90	905	7	1.81	0.81	---	4.3	345	10	38.1
577885	E	6.6	7.5	CX 200/300	90	920	7	1.81	0.71	---	4.0	355	8	38.6
577885	F	3.8	3.5	CX 200/300	80	260	10	1.77	9.38	---	14.1	105	16	40.4
577885	G	5.0	4.5	CX 200/300	80	920	6	1.81	1.80	---	7.5	255	10	27.7
577885	H	5.6	5.5	CX 200/300	80	1140	6	1.81	1.0	---	5.0	345	8	30.3
577885	I	6.0	6.5	CX 200/300	80	1320	7	1.83	1.14	---	4.1	410	8	31.1
577885	J	6.6	7.5	CX 200/300	80	1060	6.5	1.82	0.58	1.8	3.9	355	8	33.5
577885	K	5.7	5.5	CX 200/300	70	530	9	1.77	10.0	12.4	13.0	110	18	20.75
578885	L	5.9	6.5	CX 200/300	70	565	9.5	1.78	5.4	8.43	10.4	140	15	24.8
578885	M	3.3	3.5	CX 120/150	90	230	15	1.77	10.8	---	13.9			
578885	N	5.1	4.5	CX 120/150	90	875	8.5	1.78	3.7	---	10.4	185	14	21.1
578885	O	5.6	5.5	CX 120/150	90	1060	8	1.81	1.7	---	6.5	295	12	27.8
578885	P	6.3	6.5	CX 120/150	90	830	9	1.79	3.0	5.3	7.2	195	10	23.5
578885	Q	6.7	7.5	CX 120/150	90	750	7	1.80	1.4	4.7	6.7	220	10	29.3
578885	R	4.9	4.5	CX 120/150	80	375	12	1.765	6.5	10.2	13.1	65	17	17.3
578885	S	6.0	5.5	CX 120/150	80	425	11	1.78	4.2	9.4	10.4	110	14	25.9
578885	T	6.4	6.5	CX 120/150	80	400	10.5	1.77	4.9	8.6	10.2	135	15	33.75
578885	U	7.0	6.5	CX 120/150	80	615	5.5	1.78	3.2	---	7.5	210	11	34.1
578885	V	6.6	6.25	CX 200/300	80	942	5.5	1.81	---	---	5.4	350	8	37.1
578885	W	6.2	6.25	CX 200/300	80	910	6	1.80	---	---	5.7	330	11	36.2
578885	X	6.0	6.25	CX 200/300	80	1085	6.5	1.81	---	---	4.4	395	8	36.4
578885	Y	6.0	6.25	CX 200/300	80	1280	7	1.83	---	---	4.4	410	8	32.0

--- Represents unknown values due to interuptions in scheduling from numerous holidays during November.

Table 4 - Optimum Results

Soil 578885

Cenex 200/300 Penetration Asphalt

Asphalt Temperature - 330°F

2.5% Water/Asphalt Weight Ratio

The top four results of each test of Foamix made with Cenex 200/300 penetration asphalt are listed in desending order. The asphalt content, identification letter, and percentage of optimum moisture of each specimen is also listed.

Lab. No.	Avg. Stability (lbs.)	Avg. Flow (in.)	Percentage of Optimum Moisture	Asphalt Content (%)
578885 I *	1320	.07	80	6.0 - 6.5
578885 H	1140	.06	80	5.6 - 5.5
578885 J	1060	.065	80	6.6 - 7.5
578885 C	1045	.06	90	5.75 - 5.5

Lab. No.	Absorption 1 Hr. (%)	Percentage of Optimum Moisture	Asphalt Content (%)	Lab No.	Absorption 4 Days (%)	Percentage of Optimum Moisture	Asphalt Content (%)
578885 J	0.58	80	6.6 - 7.5	578885 J	3.9	80	6.6 - 7.5
578885 E	0.71	90	6.6 - 7.5	578885 E	4.0	90	6.6 - 7.5
578885 D	0.81	90	6.5 - 6.5	578885 I	4.1	80	6.0 - 6.5
578885 H	1.0	80	5.6 - 5.5	578885 D	4.3	90	6.5 - 6.5

Lab No.	Retained Stability (lbs.)	Percentage of Optimum Moisture (%)	Asphalt Content (%)
578885 I	410	80	6.0 - 6.5
578885 B	390	95	5.5 - 4.5
578885 J	375	80	6.6 - 7.5
578885 E	335	90	6.6 - 7.5

* Letters represent sample identification.

Asphalt content represents the calculated asphalt content after mixing and the asphalt content originally intended for design purposes. Since a margin of error can exist for both methods of determining actual asphalt content, both values are shown.

Table 5 - Optimum Results

Soil 578885

Cenex 120/150 Penetration Asphalt

Asphalt Temperature - 330°F

2.5% Water/Asphalt Weight Ratio

The top four results of each test of Foamix made with Cenex 120/150 penetration asphalt are listed in desending order. The asphalt content, identification letter, and percentage of optimum moisture of each sample is also listed.

Lab. No.	Avg. Stability (lbs.)	Avg. Flow (in.)	Percentage of Optimum Moisture	Asphalt Content (%)
578885 O	1060	0.08	90	5.6 - 5.5
578885 N	875	0.085	90	5.1 - 4.5
578885 P	830	0.09	90	6.3 - 6.5
578885 Q	750	0.07	90	6.7 - 7.5

Lab. No.	Absorption 1 Hr. (%)	Percentage of Optimum Moisture	Asphalt Content (%)
578885 Q	1.4	90	6.7 - 7.5
578885 O	1.7	90	5.6 - 5.5
578885 P	3.0	90	6.3 - 6.5
578885 U	3.2	80	7.0 - 6.5

Lab No.	Absorption 4 Days (%)	Percentage of Optimum Moisture	Asphalt Content (%)
578885 O	6.5	90	5.6 - 5.5
578885 Q	6.7	90	6.7 - 7.5
578885 P	7.2	90	6.3 - 6.5
578885 U	7.5	80	7.0 - 6.5

Lab No.	Retained Stability (lbs.)	Percentage of Optimum Moisture	Asphalt Content (%)
578885 O	295	90	5.6 - 5.5
578885 Q	220	90	6.7 - 7.5
578885 U	210	80	7.0 - 6.5
578885 P	195	90	6.3 - 6.5

Table 6 - Comparison of Results
By Varying the Asphalt Temperature
and Water/Asphalt Weight Ratio With Our Optimum
Moisture and Asphalt Content Mix Design

Lab No.	Asp. Cnt. (%)	Asp. Temp. (°F)	H_2O/Asp. Wt. Ratio (%)	Pct. of Opt. Mst.	Avg. Stability (lbs.)	Avg. Flow (0.01 in)	Bulk Sp.Gr.	4 Day Abs. (%)	Retained Stability (lbs)
578885 I	6.25	330	2.5	80	1320	7	1.83	4.1	410
578885 V	6.25	330	2.0	80	940	5.5	1.81	5.4	350
578885 W	6.25	330	1.5	80	910	6	1.80	5.7	330
578885 X	6.25	350	2.5	80	1085	6.5	1.81	4.4	395
578885 Y	6.25	340	2.5	80	1280	7	1.83	4.4	410

CONCLUSIONS

Although the 120/150 penetration asphalt foamed more readily, the Foamix made with the 200/300 penetration asphalt produced better results. Optimum Foamix results occurred with a water/asphalt weight ratio of 2.5% and an asphalt temperature of 330°F.

Foamix made with Cenex 120/150 penetration asphalt had better results when this particular silty-sand contained 90% optimum moisture. Foamix made with Cenex 200/300 penetration asphalt had better results when the silty-sand soil contained 80% optimum moisture. Using the optimum amounts of water and asphalt for Foamix made with 120/150 penetration asphalt, Foamix made with 200/300 penetration asphalt not only had better absorption values and comparable stabilities as mix made with 120/150 pen. asphalt, but also was able to obtain higher strength and greater moisture resistance with the addition of more asphalt and less water. Thus, not only could a stronger and more moisture resistant mix be made with 200/300 pen. asphalt, but also a greater range of asphalt and moisture content can be used to obtain values as good or better than the best values of Foamix made of 120/150 penetration asphalt. Therefore, the recommended mix design is the optimum asphalt content and moisture content of Foamix made with Cenex 200/300 penetration asphalt which is 6.25% asphalt and silty-sand containing 80% optimum moisture. The expected material properties of Foamix made at mix design (6.25% Cenex 200/300 asphalt - 330°F, 2.5% water/asphalt weight ratio, 80% optimum moisture) is as follows:

Marshall Stability - Approximately 1320 lbs.
Flow - 0.07 in.
Wet Density - 119.1 lbs./$ft.^3$
Bulk Specific Gravity - 1.83
Foaming Ratio (@2.5% H_2O Wt. Ratio, -11.0
330°F Asphalt) Half Life -30 seconds

MM/dk/23V

cc: Construction Bureau
Chuck Klimper
Ray Schaak
Ken Neumiller
Richard Wegner
Robert Rask
Mark Mullaney

MONTANA DEPARTMENT OF HIGHWAYS
Helena, Montana 59620

MEMORANDUM

TO: Duane Meiers, P.E.
District Engineer - Billings

FROM: Richard E. Wegner, P.E., Chief by Robert T. Rask
Materials Bureau

RE: ID 90-9(38)549 U-2

DESIGNATION: Wyoming Line North

LAB NO.: 578885

DATE: December 27, 1984

In regards to the memo dated December 13, 1984 concerning the Wyoming Line North Foamix base project, the foaming ratio at our recommended mix design was given as 9.3. This value is lower than the minimum requirement of 10 required in our Special Provisions. Therefore, the Cenex 200/300 penetration asphalt was retested at our mix design specifications (2.5% water/asphalt weight ratio, 330°F asphalt) to varify the validity of this value. Three foaming tests were performed on the Cenex 200/300 penetration asphalt remaining in the Laboratory Asphalt Dispenser and four foaming tests were performed on Cenex 200/300 penetration asphalt obtained from our most recent supply. The foaming ratio and half-life averaged 11:1 and 30 secs., respectively (refer to the attached foaming test results). Thus, the foaming requirements do meet our special provision requirements at our mix design specifications.

Please change the foaming ratio and half-life values listed on the final page of the aforementioned memo to their corrected values. Thank you.

MM:sk:5o

cc: Construction Bureau
Chuck Klimper
Ray Schaak
Ken Neumiller
Richard Wegner
Robert Rask
Mark Mullaney

FOAMING CHARACTERISTICS OF CENEX

200/300 Penetration Asphalt @ 330°F, 2.5% Water/Asphalt Weight Ratio

Test No.	Foamed Ht. (in.)	Settled Ht. (in.)	Foaming Ratio	Half-Life (Sec.)
1	4 5/16	3/8	11.5	33
2	5.0	15/32	10.67	30
3	5 3/16	15/32	11.07	27
				12/20/84
4	5.0	7/16	11.43	33
5	5 1/16	1/2	10.125	32
6	5.0	15/32	10.67	27
7	5 1/16	7/16	11.57	30

Average Foaming Ratio = 11.0
Average Half-Life = 30 seconds

MM:sk:5o3

MONTANA DEPARTMENT OF HIGHWAYS
Helena, Montana 59620

MEMORANDUM

TO: Duane Meiers, P.E., District Engineer
Billings District

FROM: Richard E. Wegner, P.E., Chief
Materials Bureau

Richard E. Wegn

RE: ID 90-9(62)543

DESIGNATION: Wyola-South

LAB NO.: 578885

DATE: April 15, 1985

Attached, please find the Foamix Base mix design results from material in the NE¼ of Section 30, T-8-S, R-36-E, left of centerline approximately 500', Distr. Lab.No. 510-44411-13.

The tests performed for the design of Foamix Base for Wyola South include Marshall stability and flow, bulk specific gravity, water absorption, and retained stability. Soil classification, gradation, Atterburg Limits, optimum moisture and maximum density of the soil were determined by the standard AASHTO procedure. Also an R-Value of the soil was determined (See Table 1).

Foaming Characteristics of Exxon 120/150 penetration grade asphalt were tested at various asphalt temperatures and water/asphalt weight ratios (See Table 2). This asphalt meets our special provision foaming requirements at a wide range of asphalt temperatures and water/asphalt weight ratios. Based on previous testing, optimum Foamix results occurred with a water/asphalt weight ratio at 2.5% and an asphalt temperature of 330°F.

Based on our test results (See Table 3), we recommend 6.0% Exxon 120/150 penetration grade asphalt at 330°F, a 2.5% water/asphalt weight ratio, and silty sand containing 90% of optimum moisture. The expected material properties of Foamix made at this mix design are as follows:

Marshall Stability - Approximately 1300 lbs.
Flow - 7
Wet Density - 120.0 lb./ft.^{3}
Bulk Specific Gravity - 1.82
Foaming Ratio - 13.0
Half Life - 36 secs.

If you have any questions regarding these results or recommendations, please contact us.

REW:MM:sk:lnn

cc: Construction Bureau
Chuck Klimper
Ray Schaak
Ken Neumiller
Richard Wegner
Robert Rask
Mark Mullaney

TABLE 1 - Soil Characteristics

Lab. No. 578885

Soil Optimum Moisture Content	15%
Maximum Density	108.0 lb/ft.^{3}
Liquid Limit	NP
Plastic Limit	NP
Plasticity Index	NP
Soil Classification	A-2-4(0)
% Passing 4M Sieve	* 98%
% Passing 200M Sieve	13.2%
R-Value	69

*Our Special Provisions require 100% passing the 4M sieve. Therefore, material was screened before it was used for testing. All the requirements of the Special Provision were met.

TABLE 2 - Foaming Ratio and Half-Life of Exxon AC 120/150 Asphalt

Asphalt Temp (°F)	H_2O/ASP. Wt. Ratio (%)	Foaming Ratio	Half Life (Secs.)
310	2.5	14.4	32
320	2.5	11.1	43
320	2.5	11.3	40
330	1.5	5.6	90
330	2.5	13.0	36
335	2.5	13.8	30
350	1.5	5.6	60
350	2.0	11.2	40
350	2.5	16.0	35

REW:MM:lnn3

TABLE 3 - Test Results

Lab No.	Sample I.D.No.	Target Asphalt Content (%)	Calculated Asp.Cnt. (%)	Pct. Of Opt. Mst.	Avg. Marshall Stability (lbs.)	Avg. Marshall Flow (.01 in.)	Absorption % 1 Hr.	Absorption % 4 Days	RETAINED Stability (lbs.)	RETAINED Flow (.01 in.)	RETAINED Stability (%)	Bulk Sp. Gr.	Wet Density (lb/ft³)
578885	8	4.5	4.85	80	540	8.5	4.85	11.43	160	14	29.6	1.801	116.7
578885	10	5.0	4.8	80	910	8	4.6	10.1	170	13	18.7	1.792	117.3
578885	15	5.75	5.1	80	775	8.5	5.1	11.45	150	14	19.3	1.766	116.4
578885	3	5.5	5.4	80	985	7	6.0	12.31	125	16	12.7	1.78	
578885	11	6.0	5.7	80	970	7	3.9	9.66	190	11	19.6	1.781	116.1
578885	14	6.5	5.8	80	987	6	2.7	7.66	250	12	25.3	1.793	116.7
578885	1	6.25	6.1	80	1060	8	2.0	5.8	300	12	28.3	1.80	116.0
578885	19	6.0	5.3	85	1050	7.5	2.5	6.71	330	11	31.4	1.811	
578885	12	5.0	5.0	90	1210	7.5	3.56	11.05	170	14	14.0	1.80	118.3
578885	9	6.5	5.5	90	1180	8.0	2.55	6.75	290	12	24.6	1.821	120.3
578885	18	5.75	5.8	90	1270	6.5	2.0	5.94	370	11	29.1	1.833	120.6
578885	7	6.0	5.9	90	1300	7	2.4	6.7	300	11	23.1	1.82	120.0
578885	13	6.25	6.0	90	1065	8	1.40	5.47	350	10	32.9	1.815	118.8
578885	16	6.5	6.0	90	1160	7.5	1.4	5.33	345	10	29.7	1.814	119.0
578885	17	6.5	6.1	90	1160	7.5	2.3	6.26	365	11	31.5	1.824	120.6

REW:MM:sk:lnn4

MONTANA DEPARTMENT OF HIGHWAYS
Helena, Montana 59620

MEMORANDUM

TO: Duane Meiers, P.E.
District Engineer - Billings

FROM: Richard E. Wegner, P.E., Chief
Materials Bureau

RE: ID 90-9(62)543
Designation: Wyola - South
Lab No.: 578885

DATE: May 29, 1985

The original Wyola-South Foamix Base mix design of 6.0% Exxon 120/150 penetration grade asphalt and silty-sand containing 90% of optimum moisture has been requested by the field to be changed to 6.25% asphalt and silty-sand containing 80% of optimum moisture. These are the values being used for the Wyoming Line North Foamix Base project which has the same pit source as the Wyola-South project, but is using a different source of asphalt (Cenex 200/300 penetration grade).

Since our test results were similar between the original mix design and the fields requested mix design, and because the mix would initially have less moisture in it with the new design which would cure faster and therefore may gain sufficient strength before heavy traffic is allowed on it, we feel the fields request to change design may be beneficial to their operation. Therefore, we concur with changing the Foamix design to 6.25% Exxon 120/150 penetration grade asphalt and silty-sand containing 80% of optimum moisture. However, it is critical that the moisture content does not drop below 80% of optimum because we consistently had unacceptable test results with silty-sand containing 70% of optimum moisture.

If you have any questions regarding these recommendations,. please contact us.

REW:MM:ts:3kk

cc: Construction Bureau
Chuck Klimper
Ray Schaak
Ken Neumiller
Richard Wegner
Robert Rask
Mark Mullaney

*Electronic Mail

PART II

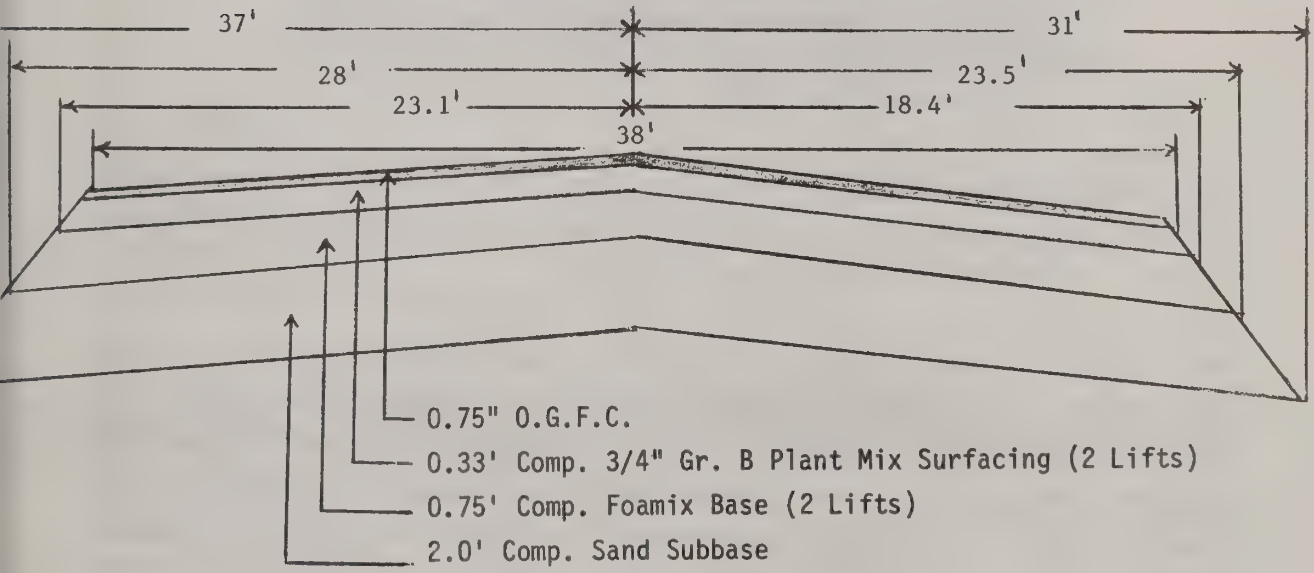
CONSTRUCTION

SCOPE

Project ID 90-9(36)531 U-2, Lodge Grass South, is 11.7 miles of 4-lane highway; project ID 90-9(62)543, Wyola South, is 5.8 miles of 4-lane highway; and project ID 90-9(38)549 U-2, Wyoming Line North, is 5.2 miles of 4-lane highway. The Wyola South project also includes an additional 1.4 miles of 2-lane connecting highway; project F 74-1(2)0 U-2, Wyola I Connection. The total length of these Foamix projects is 46.8 miles of 2-lane highway which as of this date incorporates into being the world's largest Foamix project.

The experimental roadway cross-section consists of a two-foot compacted sand subbase, two 4½ inch-lifts of Foamix, four inches of plant mix surfacing, and 3/4 inch of open graded friction course. The Foamix itself consists of silty sand, water, and asphalt mixed by a special, patented process. Foamed asphalt was produced by injecting cold atomized water, 2.5% by weight of asphalt, into the hot (330°F) asphalt. This liquid material was then immediately mixed with the premoistened silty sand to create Foamix. The physical design of the pavement and pavement base is shown in Exhibit No. 1.

Exhibit No. 1
Cross - Section of Surfacing


37'
31'
28'
23.5'
23.1'
18.4'
38'
0.75" O.G.F.C.
0.33' Comp. 3/4" Gr. B Plant Mix Surfacing (2 Lifts)
0.75' Comp. Foamix Base (2 Lifts)
2.0' Comp. Sand Subbase

CONSTRUCTION PHASE

Project: ID 90-9(36)531 U-2
Lodge Grass South

Contractor: Grading; Beyer General (Prime Contractor), Butte, MT
Surfacing; Empire Sand and Gravel (Subcontractor), Billings, MT

Empire Sand and Gravel Co. began excavating a silty sand pit source from the Murry Brown lease NE 1/4 of Sec. 25, T-7-S, R-35-E in the fall of 1984. This area is 300 feet west of Station 388+00. The top soil was removed to avoid injurious quantities of vegetable matter. The contractor was able to produce 100 to 120 tons per hour of stockpiled - 4M silty sand.

A number of screens and conveyor belts were used to obtain silty sand that met the Department's special provision gradation requirements. These gradation requirements are as follows:

Percentage by Weight Passing Square
Mesh Sieves, Montana Test Method MT-202

Sieve Size	Percent Passing
No. 4	100
No. 200	10-30

Soil Classification A-2-4(0) (Nonplastic)
R Value (Minimum) 45

Since approximately 80% of all the silty sand from this source passed the No. 4M sieve, only about 20% of the silty sand was rejected by the screening process. Therefore, no crushing was necessary.

The 2 feet of sand subbase and the Foamix base material on this project consisted of silty sand, with the exception that some of the 2 ft. sand subbase contained small amounts of clay. Intermittent portions of the silty sand used for the 2 ft. sand subbase would have passed the gradation, soil classification, and R-value requirements described previously for Foamix. However, the 2 feet of sand subbase was required to have only a minimum R-value of 21 and thus should act as additional support above and beyond the intended surfacing design. The 2 foot sand subbase serves two basic purposes. First, it allows higher average soil support for design thus allowing a thinner surfacing structure; and second, it provides a uniform subgrade, as part of the subgrade would naturally be sand.

Because the in-situ silty sand had an average moisture content of approximately 10%, water had to be added to the silty sand to obtain the desired mix design moisture content of 14.4% (90% of optimum). This was achieved by spray bars, divergence plates, and field monitoring to obtain both an accurate and uniform distribution of water and silty sand (refer to Figure-1).

Figure-1

Combining Water and Silty Sand

The premoistened silty sand was then subjected to foamed asphalt whereby the cold wet silty sand dropped into a pugmill and foamed asphalt was sprayed onto the material through special nozzles located directly above the pugmill. Subsequently, the combination of materials was mixed in the pugmill and then transferred by a conveyor belt into a stockpile.

A noteworthy observation is that highway personnel noticed that stockpiled Foamix appeared to have better asphalt dispersion than non-stockpiled Foamix. The hot weather combined with the weight of the piled Foamix may have forced the asphalt, especially if any small balls of asphalt existed, to permeate more thoroughly into the mix. Therefore, stockpiling the Foamix may have produced an unforeseen benefit.

The stockpiled Foamix was transferred to the roadway by belly dump trucks capable of carrying approximately 35 tons of Foamix per trip. A front end loader was used to fill the belly dumps (refer to Figure-2). The Foamix was placed in windrows, spread with motor patrols, and then compacted with steel and/or pneumatic tired rollers.

Figure-2
Front End Loader Used to Load Belly Dump Trucks
(Foamix was Stockpiled)

Problems Encountered

1. Originally, the foamed asphalt to be used on this project was to be supplied by Conoco, Inc., Billing, Montana. The Conoco asphalt did not meet special provision foaming requirements because Conoco, Inc. refines their asphalt with an anti-foaming agent (i.e., silicone). The application of a counteractant (Foamaid) to the anti-foaming agent improved the foaming characteristics of Conoco's asphalt, yet the foaming ratio was still below the minimum special provision foaming requirement of 10:1. Thus, Conoco, Inc. suggested that Exxon 120/150 penetration grade asphalt be used as a replacement asphalt for their 200/300 penetration grade asphalt. Since Exxon's asphalt met the special provision foaming requirements at a wide range of test temperatures, and good test results were obtained with this asphalt, Exxon AC 120/150 was approved as the Foamix asphalt binder for this project.

2. The mixing plant was a Portec unit purchased from Kolberg Manufacturing, Yankton, S.D., and is capable of producing approximately 400 tons of Foamix per hour. A few problems occurred with this equipment; such as, the main shaft in the Foamix mixing chamber broke three times and finally had to be replaced with a heavier shaft and the pugmill was remodified by shortening the length of travel of the Foamix thereby allowing less torsion on the mixing shaft (refer to Figures 3 and 4).

3. Some roadway placement problems were encountered. For instance, the Foamix was originally spread by a Jersey spreader pushed by a D8 Cat. The resulting Foamix mat had two deep parallel imprints which never would completely roll out (refer to Figures 5 and 6). Also, excess material in the spreader hopper frequently caused the front wheels of the spreader to raise off the sub-base, thus causing a fluctuation in mat thickness. Subsequently, the Foamix was dumped from trucks and spread by a motor patrol which resulted in a much better lay down operation.

4. Another problem experienced was during rolling operations wherein Foamix clung to the roller drums. Originally, rolling of the Foamix was accomplished by a pneumatic rubber tire roller followed by a steel wheel vibratory roller in a static mode. The Foamix was being picked up on the steel rollers whether the drum was dry or in a moist condition. This problem was corrected by using the pneumatic tired roller exclusively.

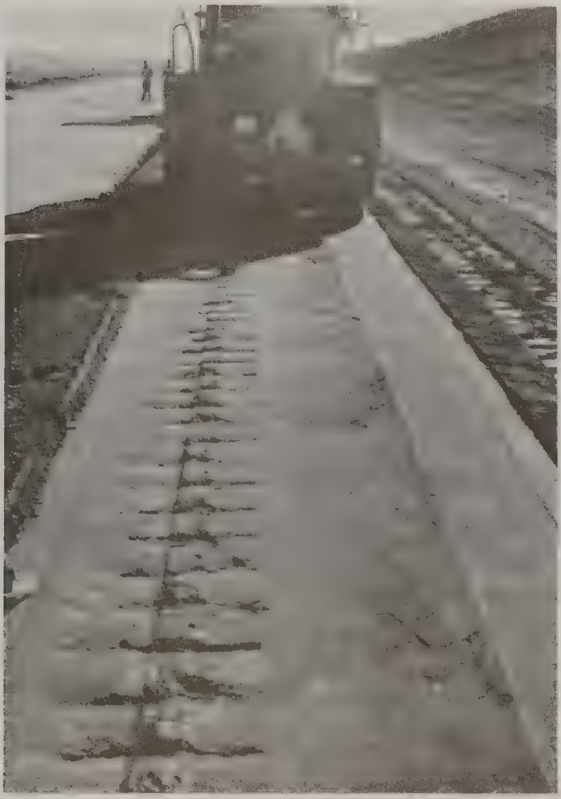
5. Water trucks were used to apply water to the Foamix material whenever the moisture content of the Foamix was too low to obtain the required 100% maximum wet density (120.0 lbs./ft^3). One of the water trucks did not apply a uniform distribution of water to the roadway and therefore the wet density of the mat fluctuated considerably. You could visually notice a strip along the mat that received most of the water. This strip had a wet density of 120 lbs/ft^3, while just outside of this strip the wet density was as low as 108 lbs/ft^3. However, after three to four passes from the roller, densities did become more uniform.

Figure-3
Broken Mixing Shaft

Figure-4
Remodified Pugmill

Figure-5
Jersey Spreader Pushed by a D8 Cat

Figure-6
Imprints That Would Not Roll Out



Consequently, the contractor elected to try and reduce the number of passes required to obtain compaction by correcting the water application spray bar. A much more uniform dispersion of water was obtained and time was also saved since the contractor was able to reach uniform compaction with fewer roller passes.

6. Reconstruction of a portion of the Foamix was necessary since once the mat cured out, it would no longer properly bond with the second (fresh) lift of Foamix. Therefore, water was added to the mat to determine if the fresh Foamix would bond adequately with the first lift of Foamix. In some cases, this method was sufficient; however, much of the Foamix required scarification and reworking to obtain adequate bonding. Scarification was performed by a typical farm disc harrow (refer to Figure-7). This problem was avoided when the contractor kept his blue-top operation in sequence with his finish operation thereby not allowing the surface to completely dry out.

Figure-7
Scarifying Foamix Mat

7. Because Conoco, Inc. recommends that the foaming pressure (water pressure) should be at least three times the asphalt pressure to avoid plugging the waterlines and foaming nozzles, the difference between the two pressures was monitored regularly. At one time, the difference in pressure was only 2.3 times more foaming pressure than asphalt pressure and a plugged nozzle problem occurred. Therefore, the contractor regularly checked to determine that the foaming pressure remained at least three times greater than the asphalt pressure and as a result no more plugging problems occurred.

8. A problem existed in obtaining sufficient minus 200M material from the silty sand. The contractor resorted to using topsoil to obtain enough -200M to meet the special provision minimum requirement of 10%.

9. Every time production was shut down, a certain amount of silty sand containing little or no asphalt would be deposited into the Foamix stockpile. This waste material had an unknown amount of asphalt in it; therefore, a problem evolved with determining the amount of asphalt being wasted. The waste material was removed from the stockpile by a front end loader and discarded. Although the wasted quantity was not measured, there was a standard deduction from the asphalt pay quantity for each shut down.

10. Since the contractor was rejecting approximately 20% of the stockpile due to the material not passing the 4 mesh sieve, the contractor requested that the +4 mesh material be utilized in the Foamix product. Additional laboratory testing indicated that the addition of +4 mesh material was detrimental to the quality of the Foamix (i.e., Marshall stabilities decreased) and therefore the contractor's request was denied. The reason the +4M material was detrimental to the quality of the mix is because it consisted of conglomerates of silty sand that would break up when compacted. This would leave dry spots that were not coated with asphalt and thus created weak spots within the test specimen.

11. Another problem that the contractor had was with silty sand containing too much water. This material would bulk and bridge in the bin prior to

going through the plant. The plant had to be stopped numerous times to unplug the bin. Once the contractor established the correct moisture content, this problem was resolved.

12. Spreading the Foamix also caused problems if the Foamix was spread too thin. A thin mat would dry out rapidly and would therefore require additional water before it would coalesce with the next lift of Foamix. Thus, the contractor found it advantageous to avoid spreading the Foamix mat too thin.

13. Problems with asphalt balling occurred periodically throughout the Foamix production stage, especially at the beginning. However, hourly foaming ratio and half-life tests performed by Highway Department personnel proved to be beneficial in keeping the asphalt balling problem to a minimum (refer to Figures 8 and 9). Asphalt balling is detrimental to the moisture susceptibility of Foamix since the asphalt will not uniformly disperse within the mix. Therefore, an inadequately bonded mix is produced. This can be caused by poor mixing and/or poorly foamed asphalt.

14. Since Foamix has the superficial appearance of containing no asphalt but consisting entirely of wet sand, a section of Foamix was unknowingly put down which contained little or no asphalt. This section was removed after vacuum extraction tests revealed a deficiency of asphalt. The Department then adopted a reduction pay scale which is as follows:

Based on Aggregate Dry Weight Asphalt Percentage	Percentage of Pay Item
5.8 + %	100% Pay
5.8 to 5.7%	90% Pay
5.7 to 5.6%	80% Pay
5.6 to 5.5%	70% Pay
5.5 to 5.4%	60% Pay
5.4 to 5.25%	50% Pay

Below 5.25% totally rejected; remove from roadway.

Once this policy was established, no more asphalt problems occurred on this project. The table on page 82 reveals the results of asphalt content checks monitored throughout the period of Foamix production.

Figure-8

Monitoring Asphalt Foaming Characteristics

Figure-9

5-Gallon Bucket Used to Measure Foaming Ratio

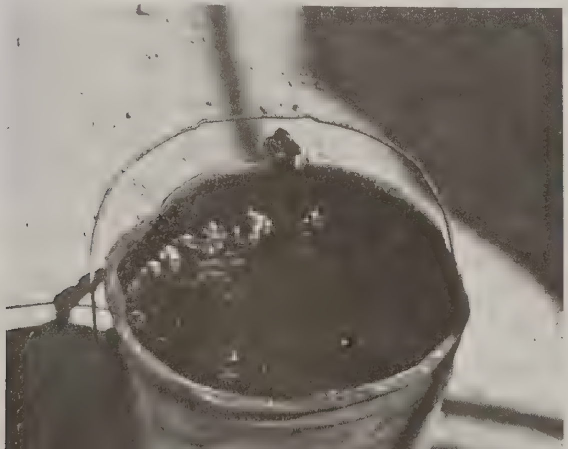


Table 1 - Random Selection of
Vacuum Extraction Test Results
Lodge Grass South

Date	Location	Asphalt Content (%) Based on Aggregate Dry Wt.
5/09/85	Stockpile	6.95
5/10/85	Stockpile	6.46
5/24/85	Stockpile	6.6
5/30/85	Stockpile	6.2
6/03/85	Stockpile	5.8
6/04/85	Stockpile	6.4
6/05/85	Stockpile	5.3
6/07/85	Stockpile	5.2
7/23/85	Windrow	7.0
7/25/85	Belt	6.2
7/26/85	Belt	1.05 *
7/26/85	Stockpile	2.05 *
7/29/85	Windrow	7.40
7/30/85	Windrow	5.40
7/31/85	Windrow	6.2

Avg. = 6.24%
Std. Dev. = 0.68%

* Excluded from Average

MARSHALL TEST RESULTS

Marshall tests of field produced Foamix were performed intermittently during construction. A random selection of the test data is given in Table -2. The Foamix was molded into standard 2.5 in., 4 in. dia. Marshall test briquets (50 blows/side, 10 lb. hammer). These briquets were oven cured three days at 96°F and then tested for Marshall stability and flow (same as laboratory design procedure). The average stability and flow of the test data is 838 lbs. and 9.1, respectively. The stability tests have a standard deviation of 542 lbs. while the flow tests have a standard deviation of 5.4.

Table -2
Lodge Grass South
Marshall Stability and Flow Test Results
of Field Produced Foamix

			Marshall	
Location	Date	Cure	Stability (lbs.)	Flow (0.01 in.)
Windrow	05/17/85	3 days 96°F	140	18
Stockpile	05/21/85	3 days 96°F	220	14
Windrow	05/22/85	3 days 96°F	640	11
Stockpile	05/22/85	3 days 96°F	550	12
Windrow	05/22/85	3 days 96°F	790	11
Windrow	05/23/85	3 days 96°F	525	16
Belt	05/28/85	3 days 96°F	160	23
Belt	05/29/85	3 days 96°F	520	12
Stockpile	05/30/85	3 days 96°F	650	9
Stockpile	06/05/85	3 days 96°F	410	10
Stockpile	06/05/85	3 days 96°F	610	8
Windrow	06/05/85	3 days 96°F	500	10
Windrow	06/05/85	3 days 96°F	705	8
Windrow	06/06/85	3 days 96°F	560	10
Stockpile	06/06/85	3 days 96°F	265	15
Stockpile	06/06/85	3 days 96°F	1210	6
Windrow	06/06/85	3 days 96°F	1200	8
Belt	06/06/85	3 days 96°F	435	11
Windrow	06/06/85	3 days 96°F	540	7
Stockpile	06/06/85	3 days 96°F	2271	10
Stockpile	06/07/85	3 days 96°F	2006	10
Belt	07/23/85	3 days 96°F	1305	8
Belt	07/25/85	3 days 96°F	1325	10
Stockpile	07/30/85	3 days 96°F	1365	8.5
Stockpile	08/07/85	3 days 96°F	1215	12
Stockpile	08/19/85	3 days 96°F	1340	9
Stockpile	08/20/85	3 days 96°F	1160	10.5
			Mean = 838 lbs.	Mean = 9.1
			St. Dev. = 542 lbs.	Dev. = 5.4

Because the Foamix mat did not cure out as rapidly in the field as Foamix that was laboratory cured, a group of tests were performed to determine what moisture content remained in the Foamix mat after a few days of curing. These test results are given in Exhibit No. 2. As can be seen, the Foamix contained a considerable amount of water even after curing for five days.

EXHIBIT NO. 2

Moisture Meter No. 0065
Attaches to D.P.M.F. No. ______

REC'D
MAY 31 1985
MAT'LS. BUREAU

STATE OF MONTANA
Department of Highways

INPLACE ROADWAY MOISTURES

Project No. ID 90-9(36) 531-U2 Report No. 1 Date 5/29/85
Termini LODGE GRASS SOUTH Contractor EMPIRE SAND & GRAVEL

TEST NO.	STATION - STATION, LANE	LIFT THICKNESS	AGE OF MATERIAL	% MOIST.	COMMENTS
1	255+00 W.B. LANE	4.5 in.	FRESH	13.2	LAID SAME DAY AS MADE
2	240+00 W.B. LANE	4.5	FRESH	12.9	AVG. 13.1%
3	225+00 W.B. LANE	4.5	FRESH	13.3	
1	255+00 W.B. LANE	4.5	1 DAY	9.3	
2	240+00 W.B. LANE	4.5	1 DAY	9.0	AVG. 9.3%
3	225+00 W.B. LANE	4.5	1 DAY	9.6	
1	255+00 W.B. LANE	4.5	2 DAYS	7.6	
2	240+00 W.B. LANE	4.5	2 DAYS	7.1	AVG. 7.4%
3	225+00 W.B. LANE	4.5	2 DAYS	7.4	
1	255+00 W.B. LANE	4.5	5 DAYS	6.5	RAINED DURING
2	240+00 W.B. LANE	4.5	5 DAYS	6.3	THE WEEKEND
3	225+00 W.B. LANE	4.5	5 DAYS	6.4	AVG. 6.4%
4	246+00 W.B. LANE	4.5	1 DAY	11.5	MADE 5/29/85
5	231+00 W.B. LANE	4.5	1 DAY	10.9	LAID 5/30/85
6	216+00 W.B. LANE	4.5	1 DAY	11.2	AVG 11.2%
4	246+00 W.B. LANE	4.5	2 DAYS	8.0	STOCKPILED
5	231+00 W.B. LANE	4.5	2 DAYS	7.1	ONE DAY, DOWN
6	216+00 W.B. LANE	4.5	2 DAYS	7.3	ONE DAY. AVG 7.5
4	246+00 W.B. LANE	4.5	5 DAYS	6.8	RAINED DURING WEEKEN STOCKPILED ONE
5	231+00 W.B. LANE	4.5	5 DAYS	6.4	DAY, DOWN FOUR
6	216+00 W.B. LANE	4.5	5 DAYS	6.5	DAYS. AVG 6.6

After compacting numerous Marshall test specimens of Foamix with the in-place moisture content, it became apparent that the test specimens were not getting adequate compaction. One sample which contained 61 percent of optimum moisture had a maximum wet density of only 100.8 lb/ft.^{3}. Therefore, the Marshall stabilities recorded for these test specimens were not a suitable indication of the in-situ Foamix strength.

With this in mind, water was added back to the Foamix samples to try and obtain the mix design moisture content (90 percent of optimum) intended for mixing and lay down operations. The test specimens were then cured at different temperatures and various time levels to determine the effect of curing in relationship to Marshall stability. Since previous in-place moisture tests revealed that the Foamix mat did not cure out any less than 30% of optimum moisture, the sample numbers marked with an asterisk are felt to be the most representative of the in-place Marshall stability (refer to Table-3).

Table -3
Lodge Grass South
Foamix Marshall Stability at Various Degrees of Curing

NO.	Initial Mst. Cnt. % of Opt.	Cured Mst. Cnt. % of Opt.	Cure Period	Marshall Stability (lbs.)
20A	90	73	2 Hrs. 96°F	295
21A	70	70	None	350
22C	94	68	6 Hrs. 73°F	360
22A	94	67	6 Hrs. 96°F	375
15A	67	67	None	215
9A	66	66	None	225
18A	88	63	3 Hrs. 96°F	440
19A	86	60	3 Hrs. 96°F	460
22B	94	58	6 Hrs. 96°F	445
21B	75	54	4 Hrs. 96°F	430
15B	75	54	4 Hrs. 96°F	315
2A	71	54	3 Hrs. 96°F	290
9B	66	51	3 Hrs. 96°F	440
23C	64	50	6 Hrs. 73°F	510
10B	63	47	4 Hrs. 96°F	245
8A	65	46	4 Hrs. 96°F	400
23A	63	45	4 Hrs. 96°F	565
1A	60	45	3 Hrs. 96°F	360
23B	67	45	6 Hrs. 96°F	535
9C	68	44	1 Day 73° F	670
18C*	88	44	1 Day 73°F	765
15C	72	41	1 Day 73°F	265
19C*	86	41	1 Day 73°F	715
21C	68	39	1 Day 73°F	400
10C	65	39	1 Day 73°F	245
11A*	82	39	19 Hrs. 96°F	1060
3B	50	37	4 Hrs. 96°F	140
2C	69	37	1 Day 73°F	555
3C	57	36	1 Day 73°F	165
8C	65	36	1 Day 73°F	400
1C	62	36	1 Day 73°F	540
20B*	90	35	1 Day 96°F	810
18B	86	34	1 Day 96°F	880
4A	55	33	1 Day 73°F	170
6A	41	32	4 Hrs. 96°F	100
19B*	88	32	1 Day 96°F	925
16C	100	32	2 Day 73°F	605
6C	47	29	1 Day 73°F	120
17C	77	29	2 Day 73°F	780
5A	57	28	2 Day 73°F	320
1B	61	26	1 Day 96°F	980
14C	84	26	3 Days 73°F	940
2B	70	25	1 Day 96°F	925
6B	46	22	1 Day 96°F	170
13C	100	22	4 Days 73°F	1010
4B	51	21	1 Day 96°F	195
17B	76	21	2 Days 96°F	990
16B	100	21	2 Days 96°F	825
11C	81	20	4 Days 73°F	1600
12C	89	19	7 Days 96°F	1165
14B	83	18	3 Days 96°F	1800
17A	78	16	3 Days 96°F	1500
16A	100	15	3 Days 96°F	1160
5B	58	14	7 Days 73°F	850
11B	81	13	4 Days 96°F	2940
12B	92	12	4 Days 96°F	2060
5C	59	10	14 Days 73°F	1240
13B	98	9	4 Days 96°F	1900
12A	90	8	7 Days 96°F	3075
13A	100	7	7 Days 96°F	2775

* Based on the initial and cured moisture content, these samples are believed to be the most representative of the Marshall stability and flow of the in-situ Foamix.

PLANT MIX SURFACING

The 3/4" plant-mix surfacing (Gr. B Anti-rutting) contained aggregate obtained from the Ed Whaley pit source Pit Lab No. 583464-474 near Hardin, Montana, 35 miles north of Lodge Grass. Sixty tests of grading were conducted on this material. The aggregate used was derived by combining 30% of the Natural Fine stockpile, 25% of the Crushed Fine stockpile, and 45% of the Course stockpile.

The plant mix surfacing was placed directly on the Foamix base without the use of either a prime or tack coat. Virtually no problems occurred; except that in one particular area, turning movements by haul trucks caused the plant mix to shove. Otherwise, the contractor had no problems with the bituminous mix slipping on the Foamix mat, nor did he have any problems with obtaining density, even with the first lift of plant mix.

COMMENTS

A sample of Foamix from a section of this project which had been exposed to the elements for approximately ten months, including one winter season, could not be obtained with an ordinary spade shovel. This area was extremely hard, even though it had rained considerably the previous evening. The slight shovel penetration into the mat showed good asphalt distribution and also indicated that the rain water had only penetrated into the mat approximately 1/4 inch. This indicates that this material should perform well as a base material.

One sample of Foamix was cored using water as a lubricant, but the specimen would not hold together. Next, a core sample of Foamix was drilled without the use of water. The drill bit became very hot and the sample could not be removed from the bit. The sample was finally removed by using a hydraulic press in the Materials laboratory. This indicates that Foamix cures out to be a very hard material but that it is also moisture susceptible when compared to bituminized plant mix.

The cost savings of using Foamix in this area were substantial because aggregate transportation and heating costs of the base material were eliminated by using Foamix. The total cost of the mixed Foamix material (delivered to the road surface) for the Lodge Grass South project was $3,770,810.00. This includes 15,292.14 tons of asphalt at $185.00 per ton and a total of 303,794.9 tons of Foamix at a bid price of $3.10 per ton.

CONSTRUCTION PHASE

Projects: ID 90-9(62)543, Wyola - South
ID 90-9(38)549 U-2, Wyoming Line North

Contractor: Grading & Surfacing; Hilde Construction, Great Falls, MT

Hilde Construction began excavating a silty sand pit source from the Padlock Ranch lease N½ SE¼ Sec. 18, T-9-S, R-36-E represented by Lab No's. 559642-48 in the fall of 1984. He was rejecting approximately 60 to 70 percent of the material in the form of chunks and lumps. Also, the material going into the stockpile was not non-plastic and PI values ranged from 1 to 6. After a couple days of screening, and since the contractor did not want to do any crushing, the contractor decided to abandon this particular source and find a new one.

With the assistance of the Department of Highways, the contractor found a second pit which was located on the Crow Tribe lease NE 1/4 of Sec. 30, T-8-S, R-36-E. This source of material was suitable for Foamix.

The contractor then moved his screening plant and began to process material in mid-October, 1984. Before winter weather set in, the contractor produced and stockpiled approximately 3% of the planned quantity of Foamix material necessary for the two projects.

Since the prime contractor for both projects was Hilde Construction and the two projects are connected, the two projects were handled as one large project. Moreover, the Wyoming Line North project area did not have sufficient quantities of suitable Foamix silty sand, based on prospecting activities, and therefore it was beneficial for the contractor to excavate one source pit near the middle of the two projects and use this source for both projects.

Eventually, the silty sand pit source was depleted. The contractor relocated his equipment approximately 500 yards north of his previous location. The silty sand in this new pit was identical to that from the previous pit and therefore no mix design changes were necessary.

The Foamix was produced from a converted CTB plant. Once a few production modifications were made, this plant was capable of producing approximately 700 tons per hour of Foamix. One significant modification was that the contractor's personnel attached an I-beam under the hopper located on top of the pugmill. This increased the capacity of the hopper which allowed a greater volume of silty sand to pass into the mixing chamber without plugging the hopper. Also, an additional conveyor belt and extra spray bars allowed a more continuous flow of uniformly mixed water and sand and thus further increased the plants production capacity (refer to Figures 10 and 11).

Figure-10
I-Beam Attached Under Hopper

Figure-11
Extra Conveyor Belt to Further Mix Water and Sand

Foamix used for these two projects contained a very clean rounded silty sand and thus the sand particles did not interlock as well as the more angular silty sand used for the Lodge Grass South project. This was reflected in the laboratory mix design test results since the Lodge Grass South Foamix had higher Marshall stability than either the Wyola South or Wyoming Line North Foamix (refer to Table - 4).

Table - 4

Comparison of Laboratory Mix Design

Marshall Stabilities of Foamix

Lodge Grass South	Wyola South	Wyoming Line North
1885 lbs.	1060 lbs.	1320 lbs.

The only difference between the Wyola South and Wyoming Line North projects was the source and grade of asphalt. Originally, Conoco's asphalt was to be used for the Wyola South project, but as mentioned previously in the Lodge Grass South Construction Phase of this report, Conoco's asphalt did not meet the special provision foaming requirements and thus a substitute asphalt was required. Special provision foaming requirements were set up to insure that the asphalt used for Foamix would achieve a desired level of foaming. Laboratory testing revealed Cenex asphalt met the special provision foaming requirements, but field tests during construction revealed that the Cenex asphalt had a slightly lower average half-life (18 seconds) than the minimum requirement of 20 seconds. However, since the time for the Foamix to travel through the contractors pugmill was approximately 9 seconds, the lower half-life was determined to be sufficient for its intent. Otherwise, the asphalt used for both projects consistently met the special provision foaming requirements.

The original mix design for the Wyola South project called for 6.0% asphalt (based on aggregate dry weight) and 90% of optimum moisture. Highway field personnel requested that this design be changed to that of the Wyoming Line North's project, which was 6.25% asphalt and 80% of optimum moisture. Since test results were similar between the original mix design and the field's requested mix design, and because the mix would initially have less moisture and therefore would cure out quicker, thus gaining strength to support heavy trucks sooner, it was felt that this mix design change would be beneficial to the project operation. Therefore, the Wyola South project mix design was approved at 6.25% Exxon AC 120/150 asphalt. Meanwhile, the Wyoming Line North project remained at 6.25% Cenex AC 200/300 asphalt. Both projects used 12% water (based on aggregate dry weight) which was 80% of the silty sand optimum moisture content.

The contractor elected not to process and stockpile the Foamix until he was able to start putting the Foamix onto the roadway. With this in mind, the contractor then decided not to stockpile any Foamix at all and just to directly unload the Foamix off a conveyor belt into belly dump trucks (refer to Figure-12).

Figure-12
Unloading Foamix Into Belly Dump Trucks
(Foamix Was Not Stockpiled)

The belly dump trucks transferred and placed the Foamix in windrows, motor patrols spread the Foamix, and vibratory steel wheel and/or pneumatic tired rollers compacted the Foamix (refer to Figure-13). Pneumatic tired rollers produced the best results and were eventually used exclusively for compaction of the Foamix base. Note: Although the motor patrols easily placed the

Figure-13

Lay Down Procedure

Foamix, controlling the width of the mat was difficult and therefore wireline control is recommended to avoid overrun costs.

Although the Foamix used on the Lodge Grass South project could support heavy traffic almost immediately after laid down, this was not the case for the Wyola South and Wyoming Line North projects. The Foamix used for these two projects was very tender after lay down and in order to avoid permanent deformation of the Foamix mat, approximately three days of curing were required before the mat gained sufficient strength to support heavy truck traffic.

PROBLEMS ENCOUNTERED

1. The contract called for an application of SS-1 at a rate of 1/10 of a gallon per square yard between the Foamix and plant mix whenever the following field conditions existed:

    (1) When the newly placed Foamix would be exposed during winter shutdown.

    (2) Whenever inclement weather was predicted while the Foamix was in the process of curing.

    (3) To control raveling.

    Therefore, an application of SS-1 was applied to the first section completed on the Wyola - South job. The SS-1 did not penetrate into the Foamix mat and would ball up on the surface when traffic drove over it. Because of these problems, an application of MC-70 was tried. The MC-70 was found to show no benefits in the bonding between the Foamix and plant mix and therefore a tack coat was eliminated from the contract.

2. Soft spots occurred in some of the Foamix mat. These soft spots were torn out and replaced with plant mix. The Project Manager required plant mix to be used as the patching material since fresh Foamix would not bond well with the cured Foamix (refer to Figure-14).

Figure-14

Soft Spots Replaced With Plant Mix

3. A significant delamination problem on the Wyoming Line North project was encountered during construction. The problem was caused by poor bonding between lifts of Foamix which were used during third pass finishing operations. This situation occurred where certain sections of the pavement, after two lifts, were not up to grade. Therefore, scarifying and reworking the third pass thin lift of Foamix was sometimes required. This problem could have been avoided if wire line control was used and if the second lift of Foamix was finished to grade at the time of placement thereby avoiding the use of third pass thin lifts.

4. A problem with moisture control existed throughout the Foamix production stage of both projects. This problem was addressed by Highway Department (State and Federal) and contractor personnel in a meeting held in the Billings District Office on May 24, 1985 shortly after construction began. Under the contract specifications, the contractor was required to determine the percentage of moisture in the silty sand that was to be used for Foamix. Attendants at the meeting decided to allow the contractor to use the State's determined moisture contents for this purpose and make adjustments by adding or subtracting water in accordance with State tests. However, it remained the contractor's responsibility to control the percentage of moisture in the silty sand prior to mixing.

State moisture tests were performed with Speedy Moisture Testers,[6] ovens, and an asphalt content gauge. A sample of Foamix from a windrow placed on the Wyola South project revealed the following test results:

Testing Apparatus	Moisture Content
Speedy Moisture Tester	12.86%
Asphalt Content Gauge	19.075 less 6.0% Asphalt = 13.075%
Microwave Oven	13.2%
Conventional Oven	12.78%

Mean 12.98%, Standard Deviation 0.193%

Based on the test results, the Speedy Moisture Tester was capable of producing accurate moisture measurements of Foamix. Since the Speedy Moisture Tester was the most convenient and time saving method of measuring the moisture content of Foamix, they were used as the State's primary moisture control of roadway placed Foamix. The microwave oven was used for primary moisture control of Foamix at the plant while a conventional oven and asphalt content gauge were used as secondary means of moisture control.

The equipment used to monitor moisture aided considerably in the moisture control of Foamix, but a complete solution to the moisture problem was never fully resolved. Adequate moisture control was eventually obtained as the plant operators gained experience but tight moisture control proved to be a difficult task due to the silty sand stockpile fluctuating from rain and evaporation. However, even though the moisture content fluctuated considerably, the overall average moisture content of freshly mixed Foamix was surprisingly close to the desired mix design value of 12.0% (Please refer to Table-5).

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[6] The Speedy Moisture Tester was developed in England and is patented by the Alpha - Lux Co., Inc. New York, N.Y.
Moisture content is determined by the calcium carbide gas pressure method.

Table-5
Random Selection of
Moisture and Asphalt Content
Test Results

		Based on Aggregate Dry Wt.	
Termini.	Date	Moisture Content (%)	Asphalt Content (%)
Wyoming Line North	5/01/85	14.3	5.8
Wyoming Line North	5/01/85	14.1	6.0
Wyoming Line North	5/01/85	11.7	5.9
Wyoming Line North	5/01/85	12.0	5.9
Wyoming Line North	5/01/85	12.8	6.3
Wyoming Line North	5/02/85	10.3	6.2
Wyoming Line North	5/02/85	10.0	6.5
Wyoming Line North	5/06/85	10.6	5.9
Wyoming Line North	5/06/85	14.5	4.6
Wyoming Line North	5/13/85	15.0	6.3
Wyoming Line North	5/17/85	11.4	6.1
Wyoming Line North	5/22/85	8.7	6.3
Wyoming Line North	5/23/85	12.4	5.7
Wyoming Line North	5/29/85	13.4	6.0
Wyoming Line North	5/30/85	13.3	5.5
Wyoming Line North	5/31/85	10.5	6.2
Wyoming Line North	5/31/85	11.5	5.5
Wyoming Line North	6/07/85	11.9	6.1
Wyola South	7/03/85	11.8	5.4
Wyola South	7/09/85	12.0	6.1
Wyola South	7/10/85	12.8	6.1
Wyola South	7/16/85	9.8	7.4
Wyola South	7/16/85	9.9	5.4
Wyola South	7/16/85	9.5	6.2
	Mean	11.84%	Mean 5.975%
	St. Dev.	1.715%	St. Dev. 0.51%

5. A section of Foamix from Station 880+00 to 902+00 was put down which contained a considerably lower asphalt content than the intended mix design. After discussing this with the contractor, the contractor hired an independent testing firm to confirm the State's test results. The testing firm found that the section which was in question did indeed contain a low asphalt content and therefore the contractor agreed to repair this test section.

The test section was torn up (refer to Figure-15) and water was added back to the material. This material was processed into two windrows. Subsequently, a motor patrol spread the Foamix into a thin lift and an SS-1 emulsion (8 lb/gal) was sprayed onto the Foamix. The Foamix was then pushed repeatedly into a pile and then spread into 3 inch lifts. An average asphalt content of 6.5% was attained and everyone was satisfied with the product.

Figure-15
Tearing Up Foamix Mat With Chisel-Tooth Plow

MARSHALL TEST RESULTS

Marshall tests of field produced Foamix were performed during the Foamix construction phase. A random selection of the test data is given in Table-6. The Foamix was molded into standard 2.5 in., 4 in. dia. Marshall test briquets (50 blows/side, 10 lb. hammer). These briquets were oven cured three days at 96°F and then tested for Marshall stability and flow (same as the laboratory design procedure). The average stability and flow of the test data is 730 lbs. and 9.9 respectively. The stability tests have a standard deviation of 328 lbs. while the flow tests have a standard deviation of 3.6.

Table-6

Marshall Stability and Flow Test Results of Field Produced Foamix

			Marshall	
Termini	Date	Cure	Stability (lbs)	Flow(0.01 in.)
Wyoming Line North	4/30/85	3 Days 96°F	245	15
Wyoming Line North	4/30/85	3 Days 96°F	650	14
Wyola South	5/01/85	3 Days 96°F	690	12
Wyoming Line North	5/01/85	3 Days 96°F	805	9
Wyoming Line North	5/01/85	3 Days 96°F	805	9
Wyoming Line North	5/02/85	3 Days 96°F	1060	6
Wyoming Line North	5/02/85	3 Days 96°F	460	10
Wyola South	5/02/85	3 Days 96°F	805	9
Wyola South	5/02/85	3 Days 96°F	915	8
Wyola South	5/08/85	3 Days 96°F	985	8
Wyola South	5/09/85	3 Days 96°F	860	8
Wyola South	5/09/85	3 Days 96°F	805	8
Wyola South	5/09/85	3 Days 96°F	165	13
Wyola South	5/15/85	3 Days 96°F	160	13
Wyola South	5/15/85	3 Days 96°F	715	14
Wyoming Line North	5/21/85	3 Days 96°F	770	8
Wyoming Line North	5/22/85	3 Days 96°F	1080	5
Wyoming Line North	5/22/85	3 Days 96°F	170	14
Wyoming Line North	5/22/85	3 Days 96°F	460	10
Wyoming Line North	5/22/85	3 Days 96°F	225	12
Wyoming Line North	5/23/85	3 Days 96°F	845	7
Wyoming Line North	5/23/85	3 Days 96°F	760	9
Wyoming Line North	5/23/85	3 Days 96°F	445	22
Wyoming Line North	5/29/85	3 Days 96°F	280	13
Wyoming Line North	6/19/85	3 Days 96°F	765	7
Wyola South	7/03/85	3 Days 96°F	935	7
Wyola South	7/09/85	3 Days 96°F	1190	5
Wyola South	7/10/85	3 Days 96°F	1165	5
Wyola South	7/16/85	3 Days 96°F	1080	9
Wyola South	7/16/85	3 Days 96°F	1230	9
Wyola South	7/16/85	3 Days 96°F	1100	8

Mean = 730 lbs. Mean = 9.9
St. Dev. = 328 lbs St. Dev. 3.6

Since the degree of curing that takes place in the field may be considerably different than the adopted laboratory cure of 3 days at 96°F, a number of in-place Foamix samples were removed from the roadway to determine whether the cured Foamix was similar to Foamix cured in the laboratory. Test results revealed that the in-place Foamix was not curing out as much as the laboratory test specimens. Therefore, a testing procedure was set up to try and obtain a better indication of the actual in-place Foamix strength characteristics. The testing procedure was performed as follows:

1. Determine in-place moisture content,
2. Add water to the Foamix to obtain the initial 80% of optimum moisture,
3. Mold Marshall test specimens,
4. Cure samples at 96°F for a given period,
5. Test samples for Marshall stability and flow,
6. Determine the moisture content of the tested samples, and,
7. Plot Marshall stability vs. cure time.

It was hoped that by curing the specimens for various lengths of time, we would obtain the moisture content presently in-place and thus be able to relate the in-place stability to that obtained from laboratory curing. Since the test results (refer to Figure-16) show that the Marshall test specimens, after curing for only two days at 96°F, contain an average moisture content of 1.57%, which is considerably lower than the average in-place moisture content of 5.55% (refer to Table-7), the test results did not turn out as anticipated. The laboratory curing procedure seems to be too extreme to accurately simulate field curing.

According to field and laboratory testing, as the moisture comes out of Foamix the strength of the material increases. Since the test specimens contained a lower moisture content than the in-place Foamix after a very short curing period and relatively low stability (avg. 460 lbs.) was obtained after laboratory curing only two days, one is inclined to believe that the in-place Foamix must have very low stability. Note: the average stability for the three day cured specimens was 1050 lbs., which is approximately 100% of that obtained for the Wyola South mix design. However, this does not seem to be the case since the Foamix mat was very difficult to penetrate into and also

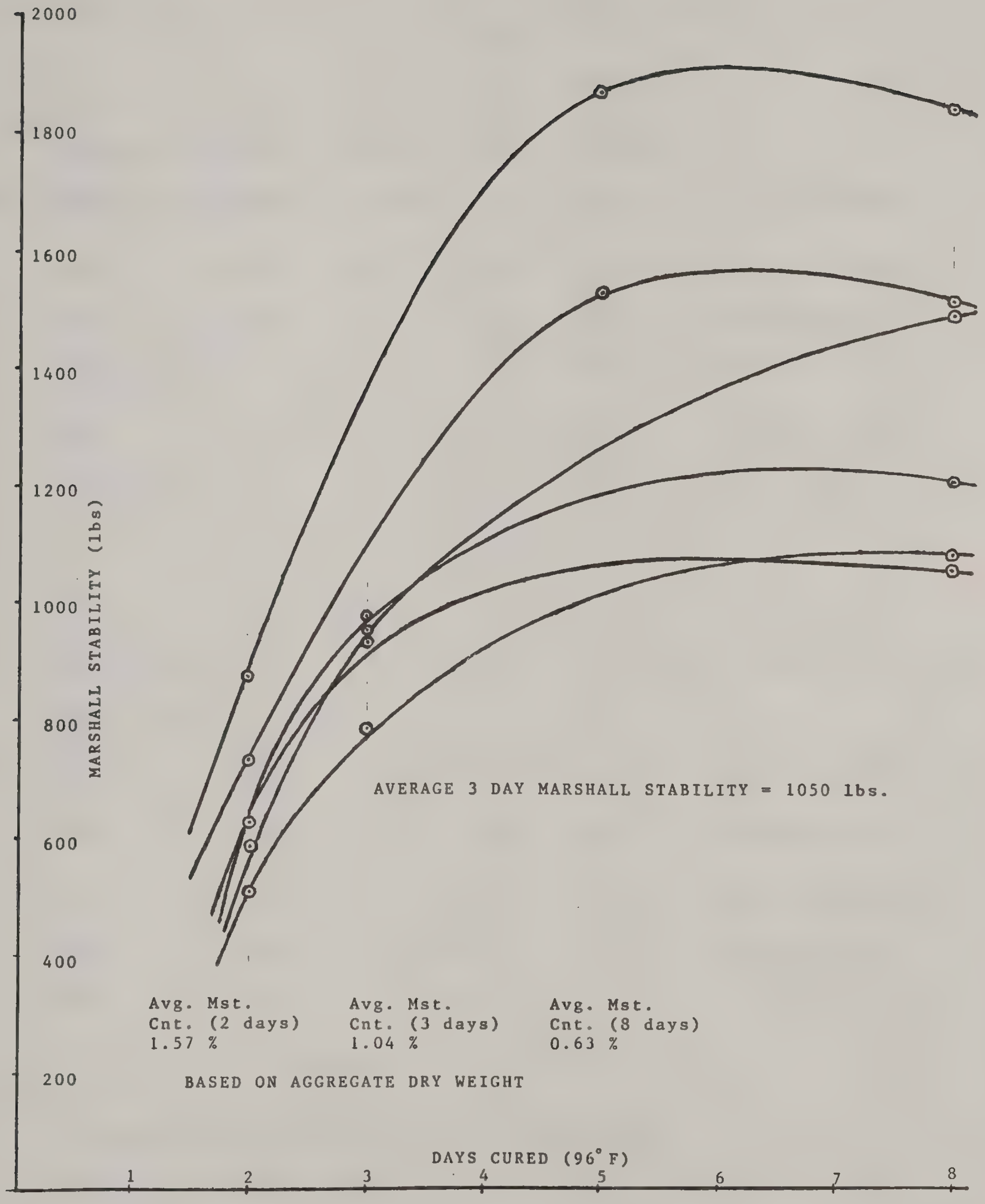

FIGURE 16. Marshall stability vs. days cured. Marshall specimens constructed from samples of in-place Foamix material. Six diverse sample sites, three tests each site. Wyoming Line-North project.

TABLE -7

MOISTURE CONTENT AND MARSHALL TEST RESULTS

SPECIMEN NO.	DESCRIPTION	INITIAL IN-PLACE MOISTURE CONTENT (%)	ASPHALT[1] AND MOISTURE CONTENT (%)	DAYS CURED 96°F	RETAINED[2] MOISTURE CONTENT	MARSHALL STABILITY (LBS.)	MARSHALL FLOW (0.01 IN.)
A_1	Wyoming Line North	5.93	18.25	2	2.24	595	8
A_2	North Bound Passing	5.93	18.25	3	1.92	960	8
A_3	Lane, Under Bridge	5.93	18.25	8	1.66	1490	8
B1	Wyoming Line North	5.58	18.25	2	1.53	595	8
B2	+1 Mi. N.B. Driving	5.58	18.25	3	0.75	980	8
B3	Lane 7/16/85	5.58	18.25	8	0.77	1220	8
C1	Wyoming Line North	3.43	18.25	2	1.51	515	10
C2	+1 Mi. N.B. Passing	3.43	18.25	3	0.91	790	9
C3	Lane. Good Shape	3.43	18.25	8	0.58	1080	9
D1	Wyoming Line North	5.75	18.25	2	0.99	630	9
D2	+1 Mi. N.B. Driving	5.75	18.25	3	0.58	940	11
D3	Lane. Just Watered	5.75	18.25	8	0.14	1050	12
E1	Wyoming Line North	5.3	18.25	2	----	740	10
E2	+1 Mi. N.B. Passing	5.3	18.25	5	1.30	1540	10
E3	Lane. Soft Spot in Road	5.3	18.25	8	0.28	1500	11

(cont'd)

---

[1] Assumed, after adding water back to the Foamix

[2] Based on assumed dry wet

SPECIMEN NO.	DESCRIPTION	INITIAL IN-PLACE MOISTURE CONTENT (%)	ASPHALT[1] AND MOISTURE CONTENT (%)	DAYS CURED 96°F	RETAINED[2] MOISTURE CONTENT	MARSHALL	
						STABILITY (LBS.)	FLOW (0.01 IN.)
F1	Wyoming Line North +1 Mi. N.B. Passing Lane. Reworked Area, Good Shape	4.54	18.25	2	1.22	880	10
F2		4.54	18.25	5	0.71	1890	9
F3		4.54	18.25	8	0.37	1850	9
G1	Wyola South 1 Mi. North of Plant, N.B. Driving Lane, Soft Spots in Road	6.1	18.25	2	1.13	905	10
G2		6.1	18.25	5	0.24	1620	8
G3		6.1	18.25	6	0.06	2010	8
H1	Wyola South, N.B. Driving Lane, Soft Spot	7.75	18.25	2	0.92	1040	11
H2		7.75	18.25	5	0.67	2040	10
H3		7.75	18.25	6	0.5	2000	10

Average
In-Place Moisture
Content = 5.55%

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[1] Assumed, after adding water back to the Foamix

[2] Based on assumed dry wt.

the majority of the Foamix mat, after curing three days, was capable of supporting heavy truck traffic with little or no deformation.

Because the Foamix samples gained further strength even though they contained very little moisture (refer to Table 7), it may be feasible to conclude that the strength characteristics of Foamix are not only dependent upon the degree in which the material cures but also the length of time in which the material cures. Thus, even though the in-place Foamix had a higher moisture content than the cured specimens, the slower rate of dehydration which occurs in the field may still be producing sufficient strength due to the longer curing process involved.

FOAMIX PRODUCTION COSTS

The total cost of the mixed Foamix material (delivered to the road surface) for the Wyola South and Wyoming Line North Foamix projects was $3,903,856.00. An individual assessment is as follows:

Project No. & Termini	Total Asphalt (tons)	Asphalt Price ($/ton)	Total Foamix (tons)	Foamix Price ($/ton)
ID 90-9(62)543 Wyola - South	8,239.71	184.00	155,589	2.971
ID 90-9(38)549 Wyoming Line North	7,479.17	190.00	138,8145	3.634

PLANT MIX SURFACING

The plant mix aggregate used for the Wyola South, Wyola I Connection, and Wyoming Line North projects was obtained from the Denius source, Pit Lab. No. 555352-365, for use as 3/4" PMS Gr. B. This aggregate was located in the NE 1/4 of Sec. 14, T-9-S, R-35-E in Bighorn County. The gradation was obtained by combining 30% of the Fine stockpile, 35% of the Medium stockpile, and 35% of the Course stockpile.

The Wyoming Line North project was designed at 6.6% 85/100 Cenex asphalt and 1.5% hydrated lime. The Wyola South and Wyola I Connection used 6.6% 85/100 Conoco asphalt and 1.5% hydrated lime.

A problem obtaining 95-100% of the recommended Marshall density with the first lift of plant mix was a common occurrence. The voids are also very high in the first lift of plant mix surfacing. This problem could have been caused from the much lower density of Foamix than that of the plant mix. However, this did not occur on the Lodge Grass South project.

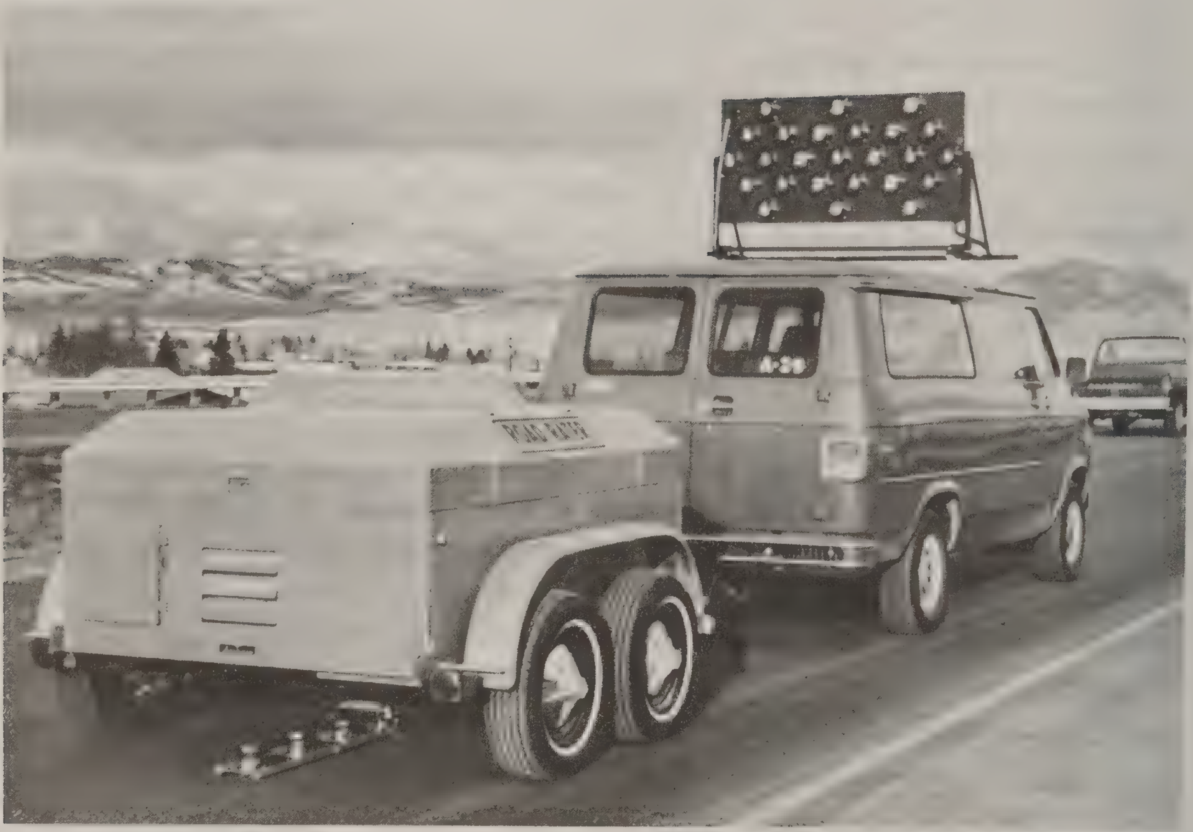
Since the contractor tried varying compaction effort by change in size, type, number pattern, and operation of rollers and still could not meet 95% density, the contractor was required to use the control strip method of determining density requirements. The control strip density was approximately 134 lb./ft^3 as compared to 148 lb./ft^3 for the Marshall density. The contractor was able to meet 95-100% of the control strip density on the entire first lift of plant mix surfacing. No problems obtaining 95-100% of the recommended Marshall density with the second lift of plant mix were encountered.

FOAMIX ROAD RATER RESULTS

Road Rater deflection testing was performed on September 11, 1985. Road Rater testing involves the application of dynamic loading applied onto a roadway surface (refer to Figure-17). Four evenly spaced transducers measure the deformation of the different material layers (i.e., subgrade, base and surfacing) as the dynamic load is applied. The elastic modulus of each material can then be calculated. Good bases should have an elastic modulus in excess of 20,000 psi and new overlays should be somewhere around 300,000 - 500,000 psi.

Figure-17

ROAD RATER



The average elastic modulus of one mile sections of Foamix for each project are listed in the following table.

TABLE-8
FOAMIX
ROAD RATER TEST DATA

Project	Milepost	Average Foamix Elastic Modulus Northbound Lane (psi)	Average Foamix Elastic Modulus Southbound Lane (psi)
Lodge Grass South	Begin Proj. MP-534	20,430	30,230
Lodge Grass South	MP 534-MP 535	21,410	30,980
Lodge Grass South	MP 535-MP 536	18,750	22,025
Lodge Grass South	MP 536-MP 537	23,210	22,750
Lodge Grass South	MP 537-MP 538	24,550	15,135
Lodge Grass South	MP 538-MP 539	**	*12,080
Lodge Grass South	MP 539-MP 540	**	*8,600
Lodge Grass South	MP 540-MP 541	**	*9,410
Lodge Grass South	MP 541-MP 542	**	*7,360
Lodge Grass South	MP 542-MP 543	**	*13,650
Lodge Grass South	MP 543-End of Project	**	12,650
Wyola South	Begin Proj. MP 545	12,750	15,020
Wyola South	MP 545-MP 546	12,930	14,320
Wyola South	MP 546-MP 547	12,135	13,020
Wyola South	MP 547-MP 548	11,140	10,990
Wyola South	MP 548-MP 549	9,350	14,260
Wyola South	MP 549-End of Project	11,020	16,720
Wyoming Line North	Begin Proj. MP 551	10,450	14,320
Wyoming Line North	MP 551-MP 552	7,540	10,500
Wyoming Line North	MP 552-MP 553	9,950	11,620
Wyoming Line North	MP 553-End of Project	9,780	10,760

*Testing was performed directly on the Foamix mat.

**Testing was not conducted due to paving and other work operations.

The elastic modulus results for the first 5 miles of Foamix on the Lodge Grass South project indicate that a good base layer exists, especially for this particular part of the state. The remaining projects had elastic modulus results typical of marginal base layers constructed in south eastern Montana.

The Wyola-South test results indicate a good base layer for this area but marginal compared to the statewide average. The Wyoming Line North test results are typical of a marginal base layer for this area but are considered weak on a statewide basis. Both the Wyola-South and Wyoming Line North elastic modulus test results were less than the highest values obtained for the Lodge Grass South project. However, some of the test results were higher than or comparable to the lower values obtained on the Lodge Grass South project.

Since the test results fluctuated considerably for all three projects and since Foamix gains strength as it cures, it is possible that the weaker areas were not cured out as well as the stronger areas and thus more strength may occur with time. Ideally, the Road Rater could have been used to monitor the strength gain of the Foamix mat as it progressively cured, the difference in strength of one layer compared to two layers, and the differences between each project. However, the Road Rater was not scheduled for any of the Foamix projects until they were to be completed and therefore only limited data was gained. Even though it is too late to monitor the initial strength gain of the Foamix mat, Road Rater tests will be performed on an annual basis and should prove to be a beneficial tool in evaluating the engineering properties of the Foamix.

Road Rater Data (Plant Mix Surfacing)

The Lodge Grass South's plant mix layers elastic modulus test results were in the range of 170,000 to 600,000 psi which indicate a very good surfacing was obtained. However, both the Wyoming Line North and Wyola South plant mix layers had an elastic modulus of 60,000 to 130,000 psi which is considered marginal to weak. Since problems obtaining density with the first lift of plant mix were encountered for both of these later projects, the Foamix base and/or the first lift of plant mix may be responsible for the low elastic modulus values obtained for the plant mix surfacing.

As mentioned previously in this report, the silty sand used for the Wyoming Line North and Wyola South projects was much smoother and cleaner than the silty sand used for the Lodge Grass South project. Thus, the smoother sand did not interlock as well as the more angular sand and therefore the Foamix engineering properties of the Wyoming Line North and Wyola South projects were less than that of the Lodge Grass South project. This is also reflected in some of the Foamix Road Rater testing. Therefore, the low plant mix elastic modulus values obtained on the Wyoming Line North and Wyola South projects can be, at least partially, attributed to the weak or marginal Foamix base.

Ride Meter Test Results

A Mays Ride Meter was used to measure the roughness of the completed projects (refer to Figure-18). The roughness is measured in total tenths of an inch per mile. Ride scores are matched up to present serviceability index (PSI) values (refer to Table-9). The PSI values reflect, approximately, the road user response to driving over a given pavement. Ride scores for each project are given in Table-10. The results indicate that at the present time all three projects have very good PSI values. Note, mile post 551-553 on the Wyoming Line North project had the best PSI value in Montana to date.

Figure-18

MAYS RIDE METER

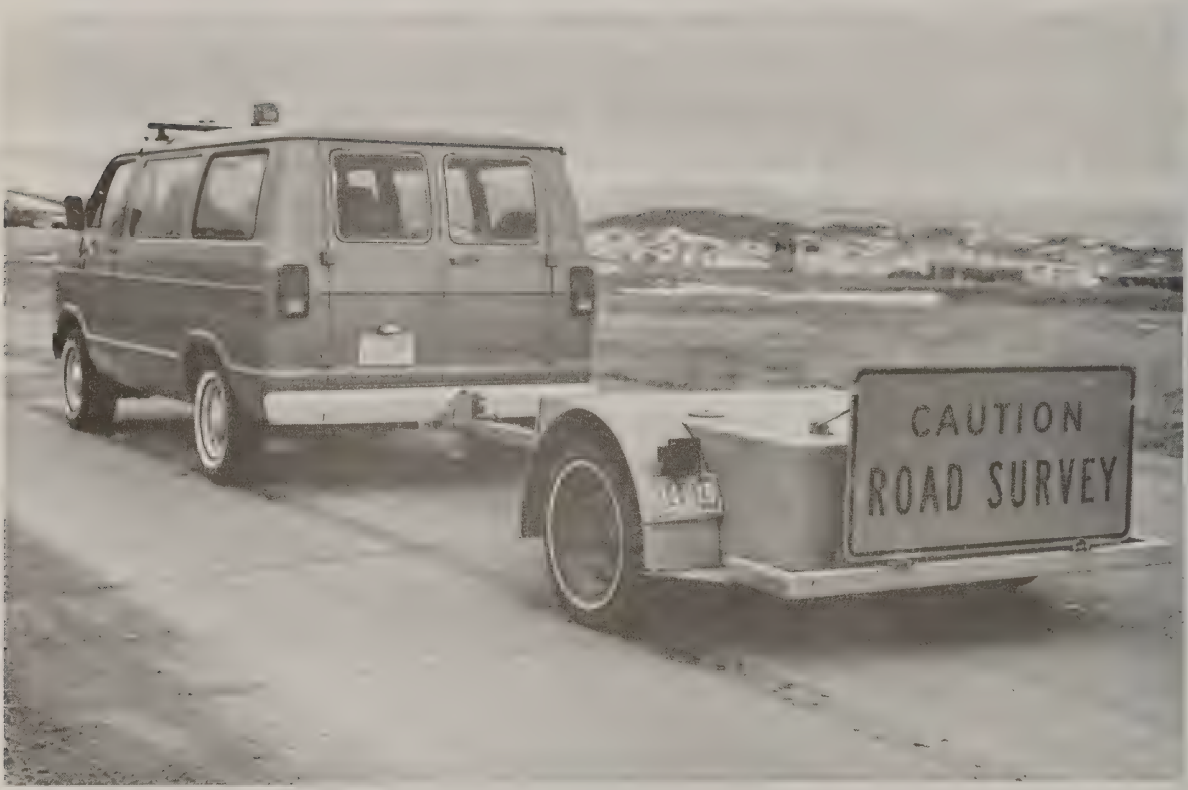


TABLE-9

RIDE SCORE VS. PSI

S	RIDE SCR	PSI
1	1	5.01845
2	2	4.98891
3	3	4.95936
4	4	4.92982
5	5	4.90027
6	6	4.87073
7	7	4.84118
8	8	4.81164
9	9	4.78209
0	10	4.75254
1	11	4.72300
2	12	4.69345
3	13	4.66391
4	14	4.63436
5	15	4.60482
6	16	4.57527
7	17	4.54573
8	18	4.51618
9	19	4.48664
0	20	4.45709
1	21	4.42754
2	22	4.39800
3	23	4.36845
4	24	4.33891
5	25	4.30936
6	26	4.27982
7	27	4.25027
8	28	4.22073
9	29	4.19118
0	30	4.16163
1	31	4.13209
2	32	4.10254
3	33	4.07300
4	34	4.04345
5	35	4.01391
6	36	3.98436
7	37	3.95482
8	38	3.92527
9	39	3.89573
0	40	3.86618
1	41	3.83663
2	42	3.80709
3	43	3.77754
4	44	3.74800
5	45	3.71845
6	46	3.68891
7	47	3.65936
8	48	3.62982
9	49	3.60027
0	50	3.57072
1	51	3.54118
2	52	3.51163
3	53	3.48209
4	54	3.45254
5	55	3.42300
6	56	3.39345
	57	3.36391
	58	3.33436
	59	3.30482
	60	3.27527
	61	3.24572
	62	3.21618
	63	3.18663
	64	3.15709
	65	3.12754
	66	3.09800
	67	3.06845
	68	3.03891
	69	3.00936
	70	2.97981
	71	2.95027
	72	2.92072
	73	2.89118
	74	2.86163
	75	2.83209
	76	2.80254
	77	2.77300
	78	2.74345
	79	2.71391
	80	2.68436

PSI	Description
5	
	(Very Good)
4	
	(Good)
3	
	(Fair)
2	
	(Poor)
1	
	(Very Poor)
0	

TABLE-10
PLANT MIX SURFACING
RIDE METER RESULTS

Lodge Grass - South

	W.B. Traff. Ln. L2	W.B. Pass Ln. L1	E.B. Pass. Ln. R1	E.B. Traff. Ln. R2
Milepost	(8)	(8)	(8)	(8)
532-533	24	12	15	25
533-534	29	14	13	23
534-535	17	15	12	18
535-536	21	14	10	18
536-537	20	14	12	19
537-538	20	12	10	19
538-539	21	15	11	23
539-540	20	14	16	20
540-541	23	14	16	18
541-542	23	14	12	22
Avg. 532-542	22	14	13	21

Wyola - South

	W.B. Traff. Ln. L2		W.B. Pass Ln. L1		E.B. Pass. Ln. R1		E.B. Traff. Ln. R2	
Milepost	(7)	(8)	(7)	(8)	(7)	(8)	(7)	(8)
542-543	--	21	--	16	--	11	--	21
543-544	--	21	--	15	--	13	--	19
544-545	19	16	24	15	20	15	14	21
545-546	18	18	18	15	12	10	15	17
546-547	15	13	15	14	16	14	14	11
547-548	16	14	15	13	13	10	12	13
Avg. 542-548	17	17	18	15	15	12	14	17

(cont'd)

Wyoming Line - North

	W.B. Traff. Ln. L2		W.B. Pass Ln. L1		E.B. Pass. Ln. R1		E.B. Traff. Ln. R2	
Milepost	(7)	(8)	(7)	(8)	(7)	(8)	(7)	(8)
548-549	17	14	18	11	12	10	12	11
549-550	22	17	17	15	11	16	17	20
550-551	17	13	23	14	11	10	14	18
551-552	20	17	20	13	16	8	20	24
552-553	18	14	22	13	14	5**	14	12
553-554	20	18	17	7	20	8	13	16
Avg. 548-554	19	16	20	12	14	10	15	17

**Lowest score recorded in Montana to date.

CONCLUSIONS AND RECOMMENDATIONS (FOR PART II CONSTRUCTION)

Conclusions

(1) A savings of at least $4,000,000.00 was obtained by using Foamix for the combined three projects. The major cost savings are due to the elimination of aggregate hauling and aggregate heating costs. Thus, for this particular area, Foamix is a worthy alternative to standard paving construction techniques.

(2) The strength of Foamix is dependent upon the ambient air temperatures in which the material cures. Higher daytime temperatures (e.g., 90°F+) caused the Foamix to cure much more rapidly than nighttime temperatures (e.g. 50°F). Therefore, the ambient air temperature during construction of these projects was beneficial to the curing process for most of the 1985 construction season. July was the hottest month on record (Avg. 24 hr. temp. = 69.3°F). Also minimal precipitation during both June and July added to the fast rate of curing. The latter part of August was colder and wetter, but the majority of the Foamix projects were completed by this time.

(3) The level of moisture in the silty sand prior to adding foamed asphalt is a critical factor. Moisture contents of about 95% optimum or greater cause the material to bulk and bridge. Moisture contents of about 70% optimum or less cause the asphalt to disperse sporadically within the mix thus creating an inadequately bonded material.

(4) The Foamix used for the Wyola South and Wyoming Line North projects was very tender after lay down. Thus, to avoid permanent deformation of the Foamix mat, approximately three days of curing were required before the mat gained sufficient strength to support heavy truck traffic. The silty sand used on these two projects was much smoother and cleaner than the more angular silty sand used for the Lodge Grass South project and therefore the sand particles did not interlock as well. This was reflected in both laboratory and field test results.

(5) A problem obtaining 95%-100% of the recommended Marshall density with the first lift of plant mix occurred with both the Wyola South and Wyoming Line North projects. The contractor tried varying compaction effort by change in size, type, number pattern, and operation of rollers and still could not meet 95% density. Finally, the contractor was allowed to use the control strip density method and was able to meet 95-100% of the control strip density on the entire first lift of plant mix surfacing. No problems obtaining 95% Marshall density with the second lift of plant mix were encountered. The compaction problems may have been due to a weak or marginal Foamix base.

(6) Foamix spread by a motor patrol resulted in a much better operation than Foamix spread by a paving machine; however, wireline control should be used. Also, spreading the Foamix too thin caused problems since it would dry out rapidly and then require additional water before it would coalesce with the next lift of Foamix.

(7) Pneumatic tired rollers produced better compaction than did steel wheel rollers. The moist Foamix tended to stick to the steel wheel rollers after one pass and therefore pneumatic tired rollers were used exclusively.

(8) Due to the size of this experimental project, time was available for determining what construction methods work best in producing Foamix. This experience will prove beneficial for any future Foamix projects.

(9) Since good laboratory test results were obtained with asphalt (i.e., Conoco) that had a lower foaming ratio than specified in the Department's special provisions, this may be an indication to lower the minimum foaming requirement in future projects. However, field test results were not as good as laboratory test results and the mixing time used in the field may not be representative of the thoroughness of mixing that occurred in the laboratory. Thus, the foaming ratio of an asphalt may be more critical in field applications due to the shorter field mixing time. Therefore, further tests should be conducted before determining what the minimum foaming ratio of an asphalt can be without being detrimental to the quality of Foamix.

(10) Overall, the Foamix operations went quite smoothly. The Foamix is expected to provide excellent strength and durability. However, the marginal elastic modulus values obtained for the Foamix and plant mix surfacing on the Wyola South and Wyoming Line North projects, combined with the high voids in the first lift of plant mix, do cause some concern. Thus, the roadway will be monitored for at least five years to evaluate the performance and cost-effectiveness of Foamix as a base course under this Interstate route (2300 ADT, 20% heavy trucks). Annual performance reports will be submitted for four years, and a final project report will be submitted in the fifth year of evaluation.

Recommendations

(1) Speedy Moisture Testers are recommended for future Foamix projects. The Speedy Moisture Tester produced accurate moisture measurements of Foamix. It was the most convenient and time saving method of measuring the moisture content of Foamix placed on the roadway. Consequently, it eventually became the State's primary method of moisture control of roadway placed Foamix.

(2) A better system should be developed to measure and adjust for moisture fluctuation in the sand during production. Moisture content in the silty sand fluctuated considerably during Foamix production.

(3) Monitoring of asphalt foaming characteristics (foaming ratio and half-life) on a regular basis, is recommended. Problems with asphalt balling occurred periodically throughout the Foamix production stage, especially at the beginning. Hourly foaming ratio and half-life tests performed by Highway Department personnel proved to be beneficial in keeping this problem to a minimum. By monitoring the foaming characteristics of the asphalt, adjustments of the asphalt temperature and water/asphalt weight ratio were made thereby decreasing or eliminating asphalt balling. Asphalt balling is detrimental to the quality of Foamix since the asphalt does not disperse uniformly within the mix thereby creating a moisture susceptible product.

(4) Reconstruction of some of the Foamix was necessary. After the initial lift cured out, the second (fresh) lift of Foamix would occasionally not bond with the first lift. Also, much difficulty was experienced with thin lifts of Foamix, that is, lifts less than the design depth. These thin lifts were used to obtain the correct grade on certain areas of the project; however, moisture in the thinner than normal lifts would dry out rapidly and thus poor compaction would result if they were not compacted immediately after placement. It is recommended that wire line control be required and the second lift be finished to grade at the time of Foamix placement. This would avoid the occasional need for scarification and relaying the material to grade.

(5) A section of Foamix was inadvertently put down which contained little or no asphalt. Foamix meeting the design specifications has the superficial appearance of containing no asphalt (it looks like wet sand). The appearance of Foamix is therefore an unreliable way to monitor asphalt content. In addition, daily asphalt content checks (i.e., gross tank measurement methods) were too infrequent and too unrealiable to detect numerous variations which occur during daily production. Therefore, asphalt content should be monitored both with increased frequency and by more reliable test methods. Vacuum extractions on a routine basis, e.g.,four times/day, are recommended.

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